Evaluating Culvert Bat Gate Use at Underground Mines: A Review

U.S. Department of the Interior
Office of Surface Mining Reclamation and Enforcement

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Cover. Multiple culvert style bat gate with angle iron bars in North Central West Virginia. Image credit: Jenna Hincks, OSM.

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Introduction

This review of the literature aimed to compile and analyze information pertaining to the efficacy and current state of the science on culvert bat gate use at underground mines in the Appalachian Region[1]. The information from this review is intended to provide information on the efficacy of culvert bat gates and general recommendations when evaluating a site for installation of a bat gate. Because of the minimal research on bat gate performance and use by bats, the scope of the review is national in scale, does not solely review studies on eastern coal mines, and contains gray literature. The literature review was conducted in the spring of 2019. Keyword searches were conducted throughout online databases such as JSTOR, Google Scholar, Research Gate, Springer Link, and Wiley using a combination of the keywords: bats, gates, obstruction, mines, culverts, myotis, caves, and Chiroptera. Backwards and forward reference searching was completed, additional gray literature (unpublished or noncommercially published research) were obtained through OSM staff, and the compiled references were organized using a reference management software. This review is structured to: 1) briefly explain the relationship of bats with abandoned mines, 2) provide an overview of the federally listed bats known to the Appalachian Region, 3) detail the design of two commonly-used bat gates in the Appalachian Region, 4) highlight multiple bat gate studies reviewed, and 5) list management recommendations.

Abandoned Mine Lands

Human Safety

Surface and underground mining in the Appalachian Region date back to the 1800's with mining on Mt. Washington in Pittsburgh, PA occurring as early as the 1760's. Prior to the Surface Mining Control and Reclamation Act (SMCRA) of 1977, mined lands in many states were not required to be, and frequently were not, restored to their original land use and/or reclaimed to original contours. These abandoned mine lands (AML) now dot the landscape throughout the region and pose a risk to human safety and the environment. Whether the AML hazards are abandoned highwalls, adits, steep slopes, portals, or shafts, humans who explore these areas are at elevated risk of being harmed. Injuries may occur through entrapment in the abandoned underground mine workings, as a result of rock falls at a highwall, falls into shafts, or due to exposure to anoxic or toxic/explosive internal atmospheres. State AML programs, along with OSM, are tasked with prioritizing and reclaiming AML sites in the Appalachian Region. Sites which pose a risk to human health and safety are the highest priority for reclamation under AML programs. Mine openings pose a significant threat to human health and safety, as openings are typically highly weathered and support structures have often failed or been removed. Additionally, openings provide access to underground mine workings which are all in various states of collapse. Individuals that enter underground workings are at risk of internal collapse, lethal atmospheres, and falls down steep slopes. There are many examples of underground explorers becoming lost, trapped through collapse, or killed by lethal gasses. When these events happen, rescue teams are dispatched to rescue survivors or retrieve bodies. These efforts expose rescuers to the same dangerous conditions encountered by the

[1] For the purpose of this review the Appalachian Region consists of the following states: Tennessee, Kentucky, Virginia, West Virginia, and Pennsylvania.

victims. There have been several incidents in which rescue team members have been injured or killed during these recovery efforts. Historical mine workings are an attractive nuisance that draw the curious, collectors of antiquities, and those determined to explore underground workings. As such, the reclamation of mine openings is prioritized. However, reclamation is complicated by the use of abandoned mines by bats, with this relationship varying from casual (Guild 3) to obligatory (Guild 1-Sherwin, Altenbach, and Waldien 2009). The USFWS has stated that abandoned mines serve as valuable habitat for a wide range of species of bats. Consequently, the closure of abandoned mine openings can constitute a loss of habitat, and portal reclamation may adversely impact threatened and endangered bat species.

Bat Use

Abandoned mine workings are highly variable in depth, complexity, and available micro-climates. As a result, subterranean conditions may be conducive to use as maternity roosts that include pre-birthing, birthing, and weaning activities. Other types of use include hibernation (cold season use where bats lower metabolic rate to ambient conditions), bachelor roosts, night roosts, transient roosts, migratory stopovers, swarming sites, mating sites, foraging sites, drinking sites, or refugia for bats, including threatened and endangered species (Hall et al. 1998; Johnson, Wood, and Edwards 2006; Sherwin, Altenbach, and Waldien 2009). Depending on the internal mine configuration and airflow, bats may be capable of using different features of a mine due to the spatial and temporal variability of microclimates (Brack Jr. 2007; Perry 2013). Abandoned underground mines may provide habitat in a landscape, where there wasn't any prior to mining, thus allowing a species to extend the peripheral and intra-range distributions. Changes in distributions resultant from the development of abandoned mines has been discussed by Hall et al. (1998), and Sherwin, Altenbach, and Waldien (2009).

The requirements of AML programs to protect the public from the dangers associated with abandoned mines, and concurrent need to maintain use of important roosts by bats has been resolved with the inclusion of bat gates as a closure tool. Bat gates are intended to preclude the public from entry into abandoned mines while promoting access to these same mines by bats. Thousands of bat gates have been installed at mine openings throughout the United States, with constructions including a broad range of materials and design. The lack of programmatic-scale monitoring of bat use at mines prior to and following gate installation makes it difficult to diagnose the meta-responses of bats to gate type and impossible to understand more subtle responses of bats to gates. Different species have different general responses to gates and may further vary based on the type of use realized within the mine. Any modification of mine openings has the potential to dramatically alter the subterranean atmosphere which may reduce, alter, or promote the use of these new conditions by bats.

The quality and integrity of bat gate materials vary, reflecting program budgets, size, shape and stability, and pH levels of the substrate of mine openings. Abandoned mine openings are highly variable and inherently unstable. As a result, site specific modifications of generic gate design and materials are often necessary to install a secure gate. While promotion of use by bats is an important component of gate design, the gate must also be sufficiently robust to preclude human access. The resultant variability of gate structure has led to concern about the impact of bat gates that vary from the generic designs typically followed. In fact, the failure to modify gate design and material to site specific conditions often results in bat gates that fail to promote use by bats and/or are structurally compromised. Any modification of mine openings potentially impacts subterranean conditions of associated workings. Excavation of openings for gate installation, and the design and materials used to build gates may restrict air flow, alter internal temperatures and availability of microclimates throughout the workings,

and/or dramatically alter internal humidity. It is possible that portal modifications will alter the specific assemblage, and types of use that existed prior to installation of bat gates. Simply put, the gate should allow for maintenance of airflow, and be of a design conducive to use by the target (Vories and Throgmorton 2000), while concurrently restricting access to the mine by the public (Sherwin, Altenbach, and Waldien 2009). The installation of a bat gate precludes human entry, greatly reducing potential human disturbance to bats. At sites where human disturbance is the primary constraint on use by bats the patterns of use often dramatically change as bats are released from this limiting factor. Without robust pre-closure data it is impossible to understand the direct impacts of bat gate design on post-gating use by bats. Only when bats are proven negatively impacted by the gate, such as mortality from impacts of bats with gates, can direct association be drawn.

Many factors may affect whether a mine is used by bats after gating. The addition of the gate may not be the only factor affecting bat behavior at a site. Altered behavior can result due to external influences, such as nearby logging or other land use changes, and may impact bat usage of a gated mine (Kennedy 2002b). Additionally, AML programs often include the reclamation of many openings within the landscape with most being closed through hard closure (backfill). This dramatic alteration of the subterranean landscape surrounding the gated opening(s) is likely to cause perturbations throughout the landscape. During the installation of a bat gate, the removal or partial destruction of vegetation may affect bat usage of the mine, as a result of changes to the microclimate near the entrance. Additionally, even if an accurate mine map exists for an abandoned underground mine, the workings may have been impacted by roof falls and collapse, thus making it difficult to fully understand the dynamics of the internal air flow and to predict the resulting microclimate post-gating. It is important to remember however, that abandoned mines are structurally dynamic with portal subsidence, internal collapse, and collapse of interconnected openings. With this in mind, it must be understood that roosting bats have likely experienced some alteration of internal structure (and associated micro-climates) during their lifetime.

Bat Species in the Appalachian Region

There are seventeen[2] species of bats known to the Appalachian Region (Table 1).

Table 1. Bat species known to the Appalachian Region. ("Bats of West Virginia" 2007; Stihler 2012a; Kentucky Department of Fish & Wildlife Resources 2014; Virginia Department of Conservation & Recreation 2015; Commonwealth of Pennsylvania 2017; Tennessee Wildlife Resources Agency 2020).

Gray bat (*Myotis grisescens*)	Hoary bat (*Lasiurus cinereus*)
Small-footed bat (*Myotis leibii*)	Evening bat (*Nycticeius humeralis*)
Little brown bat (*Myotis lucifugus*)	Seminole bat (*Lasiurus seminolus*)
Indiana bat (*Myotis sodalis*)	Silver-haired bat (*Lasionycteris noctivagans*)
Northern long-eared bat (*Myotis septentrionalis*)	Red bat (*Lasiurus borealis*)
Big brown bat (*Eptesicus fuscus*)	Rafinesque's big-eared bat (Corynorhinus rafinesquii)
Virginia big-eared bat (*Corynorhinus townsendii virginianus)*	Eastern pipistrelle (*Pipistrellus subflavus*)
Southeastern myotis (*Myotis austroriparius*)	Brazilian free-tailed bat (*Tadarida brasiliensis*)

[2] Seventeen species have been documented however, not all species may reside in all states and presence may be unlikely.

Eastern Big-eared Bat (Corynorhinus rafinesquii macrotis)	Northern Yellow Bat (Lasiurus intermedius)

Not all bat species use subterranean habitats in the same way, and dependence on roost availability across the landscape varies by species (Sherwin, Altenbach, and Waldien 2009). Bats may use caves and/or abandoned mines for roosting activity during the day, or at night to rest between foraging (Stihler 2003). The endangered *Myotis sodalis* (Indiana bat), endangered *Corynorhinus townsendii virginianus* (Virginia big-eared bat), endangered gray bat (*Myotis grisescens*), and threatened *Myotis septentrionalis* (northern long-eared bat) all use subterranean habitat in part of their life history (Currie 2000; Sherwin, Altenbach, and Waldien 2009; Gannon and Bovard 2016). The following are brief descriptions of the use of underground mines by four federally-listed bats known to the Appalachian Region.

Gray bat

The gray bat (*Myotis grisescens*) was listed as endangered in 1979. Gray bats inhabit caves or mines year round, may form large colonies and may be capable of using colder mines and caves (Tuttle and Taylor 1994). Gray bats use different caves in summer and winter, hibernating in caves with cold air traps and forming maternity colonies in caves with warm air traps (Harvey 2000). Because gray bats form large nursery colonies they may not use gated sites with constricted openings (Tuttle and Taylor 1994). Maternity roosting gray bats typically won't use full gate sites but will at hibernation sites (Currie 2000).

Virginia big-eared bat

The Virginia big-eared bat (*Corynorhinus townsendii virginianus)* is a subspecies of Townsend's big-eared bat (*Corynorhinus townsendii)* and was listed as endangered in 1979. The Virginia big-eared bat is a medium size bat, characterized by large ears, which inhabits caves or mines year-round (USFWS 2011). Virginia big-eared bats require differing microclimates for different roosting behaviors, and may use different caves in the winter than in the summer. Maternity colonies use warmer portions of caves in the summer and hibernate in cooler portions during the winter (USFWS 2011). Virginia big-eared bats have been shown to inhabit gated abandoned coal mines in West Virginia and have been shown to routinely use roosts protected with full gates (Currie 2000; Johnson, Edwards, and Wood 2005).

Indiana bat

The Indiana bat (*Myotis sodalis*) was listed as endangered in 1967. The Indiana bat is a medium-sized bat with dull grayish-chestnut dorsal fur and light brown ventral fur (Thomson 1982). Indiana bats use caves and mines as winter hibernacula and may hibernate in clusters in cooler sites (Thomson 1982; Butchkoski et al. 2016b). Swarming at hibernacula occurs from August through October, with the majority of mating occurring during this period (Thomson 1982). Indiana bats have been observed in large numbers at mine locations and readily accept full gates at roost sites (Currie 2000; Vories and Throgmorton 2000).

Northern long-eared bat

The northern long-eared bat (*Myotis septentrionalis*) was listed as threatened in 2015 with a section 4(d) rule. The northern long-eared bat is known to hibernate in caves and abandoned mines (Caceres and Barclay 2000). Northern long-eared bats emerge from their hibernacula in the spring, and move to their summer roosts under exfoliating bark of second-growth forests (Foster and Kurta 1998). Males and non-reproductive females roost separately and may also temporarily roost in caves and mines (Caceres and Barclay 2000). They may roost individually or in small groups, with reproductive females forming larger groups, known as maternity colonies. Northern long-eared bats are known to use cave or abandoned

roosts in the summer and have been known to accept full gates at winter roost sites (Currie 2000; USFWS 2015).

Bat Gate Designs

First and foremost, bat gates are installed at underground mine openings to prohibit humans from entering the dangerous abandoned mine workings. Secondarily, for bat conservation, the objective is to provide, or preserve, potential habitat thereby maintaining populations across the landscape (Sherwin and Altenbach 2002). Early designs by Hunt and Stitt (Cave Gating, 1981) were initially intended (designed) to keep humans out, but they did not adequately address biological impacts to bats (Hunt and Stitt 1981; Kennedy 2002a). Bat gate designs have evolved since the initial gates in the late 1970's, with improvements to standard designs since those early gates (Elliott 1996). Bat gate design typically depends on the type of opening to be gated, e.g., portal or shaft (Tobin and Chambers 2017). An portal is a horizontal passage leading into a mine workings, while a shaft is oriented vertically. Most candidate gate sites in the Appalachian Region are portals, so the standard bat gate and the culvert bat gate are the typical gate designs utilized.

Standard

The standard bat gate design consists of a grid of bars placed horizontally across the cave or mine opening (Figure 1). The spacing between horizontal bars is critical in allowing access of bats and other small mammals, while prohibiting human entry. The bars are typically constructed of 4" angle iron, oriented with the apex facing up and 5 ¾" of space between the bars. This design is thought to maximize the airflow exchange between the surface and subterranean environments (Elliott 1996; Vories and Throgmorton 2002). Bars are oriented horizontally, with vertical supports spaced greater than 24" apart, to allow bat passage. This basic design is widely used even at mine openings where there are no bats currently present (Fant et al. 2009). Variations on the basic gate design include half gates for areas where the opening is tall, and standard gates with "windows" where there are large numbers of bats using the cave. Vandalism is the most common maintenance issue with standard gates. Due to the unstable geology of mine portals in the Appalachian Region, the standard gate design may not be feasible in all situations.

Culvert

Culvert style gates are typically installed in portals where overburden instability presents the risk of collapse and precludes the safe installation of a standard gate (Langdon 2002; Sanders Environmental Inc. 2006). Culvert style gates consist of a length of culvert and a closure device to deter human entry (Figure 2). Culverts vary in diameter, from as small as 24" to greater than 60", and are constructed of either smooth or corrugated steel, aluminum, concrete, high-density polyethylene (HDPE), or polyvinyl chloride (PVC). Culverts are designed to fit the opening of the portal diameter and extend into the portal for a length of 10' or more until reaching stable substrate and the height of the highwall to backfill. Closure devices are typically constructed of round bars, angle iron, or angle HDPE, when vandalism/theft is a major concern. Closure devices may be installed either on the outside of the culvert or recessed within the culvert, and may use a similar design as standard gates. Once culverts are placed, they are typically backfilled with soil and rock located onsite, or polyurethane foam may be used to seal between the culvert and the portal opening. Culverts have been used to protect mines housing a variety of bat species for hibernation, maternity, migratory stopover, and night roosts (Sherwin, Altenbach, and Waldien 2009).

Figure 1. Standard gate at abandoned underground mine portal in North Central West Virginia. Gate constructed of angle iron. Image credit: Jenna Hincks, OSM.

Figure 2. Thirty-six-inch diameter culvert bat gate installed at an abandoned portal in North Central West Virginia. Culvert constructed of HDPE with angle HDPE closure. Image credit: Jenna Hincks, OSM.

Bat Gate Studies

Eastern U.S. Studies

A 2002 study in West Virginia indicated that, prior to white nose syndrome (WNS), bat presence could best be explained by the mine entrance shape and the density of bat gates in an area. The study found that in isolated areas, more species were present (Johnson, Wood, and Edwards 2006). In this study, the isolated gate sites, i.e. gates at the greatest distance from other known gates, showed the most species diversity. However, clustered gate sites may host a wider range of roost conditions, provide redundancy, and often realize dynamic patterns of roost use. Isolated mines may provide the only available roost on a landscape scale (Johnson, Wood, and Edwards 2006; Sherwin, Altenbach, and Waldien 2009; Tobin et al. 2018).

A 2006 report for the WVDEP Office of Abandoned Mine Lands & Reclamation (OAMLR), prior to the onset of WNS, was inconclusive in regards to the effect of culvert bat gates on bat presence. The study used mist nets and harp traps to capture bats prior to (2005), and following (2006), culvert bat gate installation at six portals in Kanawha and Putnam counties, West Virginia. Two portals showed an increase in the number of bats captured (one bat per portal), three showed no bats pre or post installation, and one portal showed a decrease in the number of bats captured (eight bats in 2005 and none in 2006). The absence of bats captured post construction at one portal is most likely attributed to the culvert being 90% obstructed with fill. Based on these findings, no definitive conclusion on the effect of the culvert gate on bat use may be made from this study (Isaac, Lowe, and Colyer 2006).

A 2007 report for the WVDEP OAMLR evaluated bat presence at locations with and without bat gates installed in West Virginia (Sanders Environmental Inc. 2007). Bats were captured at four (Lamberts Run, Ring Hollow, Possum Hollow 3A, and Possum Hollow 4A) of the eight portals in this study, during two previous sampling efforts for WVDEP prior to gating (Isaac, Lowe, and Colyer 2006; Sanders Environmental Inc. 2006). Bat activity at Lamberts Run increased following culvert gate installation. Bats were captured at Ring Hollow prior to gating but not afterwards. Bats were captured at Possum Hollow portal 3A pre and post culvert gate installation, and one bat was captured at Possum Hollow portal 4A post installation in both 2006 and 2007, despite none being captured in 2005 prior to installation. This report showed that bat use of a portal is temporally variable and was observed specifically for the northern long-eared bat, at a culvert gate.

A 2014 study, funded by OSM to evaluate the use of culvert gates in West Virginia, sampled 38 portals. These 38 portals were located among 12 abandoned mine sites, with 37 containing culvert gates and 1 containing a standard gate. A total of six bats were captured over the course of the study at three sites. Bats were captured at three culvert gates and at the lone standard gate. Bats were not captured at the Lamberts Run Site, where 32 bats had previously been captured in 2007. Fewer bats were captured at Possum Hollow (all portals) than during the previous WVDEP studies. Because there was minimal pre-gate bat usage data, and because this study occurred post – WNS, no definitive conclusion may be drawn on impacts to bat activity due to the installed gates (Sanders Environmental Inc. 2014).

Survey methodology varied across the above summarized studies for the WVDEP and OSM. In Isaac (2006) and Sanders (2006 and 2007), portals were surveyed for two consecutive nights. In Sanders (2014), portals were surveyed for two non-consecutive nights, with at least two weeks separating the sample nights. Additionally, the Possum Hollow portals are enumerated differently in Sanders 2014 than in the previous studies, and consequently, a clear comparison among the specific portals surveyed in 2014 and in previous years cannot be made. Thus, although the same portals were sampled multiple

times, the results of the 2014 report may not be comparable to previous efforts, due to these differences in the methodology. Finally, because surveys occurred pre and post onset of WNS in West Virginia, it is difficult to attribute any change in bat presence/activity seen in these reports to the installation of a bat gate, as WNS has significantly reduced the bat population in the state (Stihler 2012b).

Additional Studies

In the western U.S., Tobin and others (2018) show that, in the short-term, bats may respond negatively to gates. Initial negative effects may be attributed to the individual effect of the gate, or a more synergistic effect, involving multiple factors. Ecological and life history considerations, such as echolocation characteristics, maneuverability/agility, and roost type or degree of site fidelity (tendency of a bat to stay in or habitually return to a particular area) may all affect whether a gated site provides suitable habitat for bats. These factors, in combination with environmental effects of decreased portal size, microclimate alteration, or availability of other roosts in a landscape, are variables that may also lead to discontinued use of a mine. However, over time bats may adjust to the gate, and negative effects may decrease (Diamond and Diamond 2014; Tobin et al. 2018).

A western U.S. study by King (2005) concluded the effect of culvert gate closures on microclimate is the same as if the mine were lengthened. However, King only studied three culvert sites and reported the results as inconclusive. Additionally, a study of culvert gates in Montana showed continued use of culvert gate sites by Townsend's Big-eared bat (of which Virginia Big-eared bat is a sub-species) at multiple abandoned mine sites (Hendricks 1999).

Gating a mine opening, instead of permanently sealing it, may allow the mine to be used by bats and other animals, if suitable (Fant et al. 2009). Underground mines may provide suitable roosting and hibernacula conditions, similar to natural caves, for bats and may provide important habitat within a bat's range (Altenbach and Sherwin 2002). Studies have shown that bat use decreases in the short term at sites where gates have been installed; however, bat use may increase over time (Sherwin and Altenbach 2002; Derusseau and Huntly 2012; Tobin et al. 2018). A review of the literature by Tobin and Chambers (2017), found that the long-term (studies with greater than five years of data) response of Indiana and gray bats to caves with standard angle iron gates was positive (Tobin and Chambers 2017). The same study also found that old gate designs such as stone walls, iron doors, or cement should not be used because of presumed effects to subterranean microclimate (Tobin and Chambers 2017).

Summary

Results on the effect of culvert gates to bat use are inconclusive. However, some post-closure evaluations indicate that bats continue to use sites where culverts are installed (Hendricks 1999; Sanders Environmental Inc. 2007; Sherwin, Altenbach, and Waldien 2009). In a literature review, Tobin and Chambers (2017) identified three culvert gate studies. Results were positive for the studies, but with such a small number of study locations, the effect of a culvert gate could not be determined. No studies comparing the various types of culvert material (e.g., PVC, HDPE, steel, corrugated, etc.) could be located, so therefore it is unknown at this time if different materials affect bat behavior differently.

Conclusion and Recommendations

Conclusion

A review of the literature provides no conclusive evidence on the efficacy of culvert bat gates and no clear alternative to this type of gate for closure of unstable underground mine openings to protect the

public from AML hazards while concurrently maintaining subterranean bat habitat in the Appalachian Region. Because roost fidelity and bat behavior vary between seasons, among years, and species, the use of mines by bats, and therefore the effect of the gate on bat use, is unclear (Sherwin, Altenbach, and Waldien 2009; Butchkoski et al. 2016a). Sherwin and Altenbach (2002) describe the state of the science on responses of bats to gates, and highlight a paucity of scientifically rigorous data, to understand bat responses to gates. While the number of peer-reviewed studies has increased since Sherwin 2002, most information is anecdotal, and there remains a lack of scientifically-rigorous data to guide management decisions (Sherwin and Altenbach 2002; Furey and Racey 2016). Most studies have design issues and are either gray literature, lack pre-gate baseline data, or are not conducted at a landscape scale to assess relationships between the population and community (Herder 2002). Furthermore, most study sites in the literature are caves or Western United States mines which have easy access and stable large openings not typical to the Appalachian Region. Research has historically focused on the assessment of individual gates and changes to the number of individuals using a particular roost over a short temporal period (typically two years). This design does not take into consideration that individuals or a colony may not exhibit fidelity to a site year after year, and thus results may not accurately reflect the failure, or success, of a gated site. Similarly, the lack of studies with pre-gate installation and longer post-gate temporal data does not allow for analysis of whether the gate design has affected internal cave conditions such that roost use has changed, e.g., from a maternity roost to bachelor roost (Sherwin and Altenbach 2002). Additionally, no study could be located evaluating the effect of culvert length or culvert material on bat behavior. Finally, this review acknowledges WNS is significantly affecting bat populations, and therefore it is difficult to determine the impact on the use of gated underground mines.

General Recommendations

Sites which pose a risk to human health and safety are the highest priority for reclamation under AML programs. USFWS has stated that bats may use abandoned underground mines as valuable habitat. Therefore, bat use must be taken into consideration when addressing the human health and safety issue at an abandoned mine.

Due to multiple factors, it is difficult to definitively determine the effects of culvert gate installation on bat presence and activity at abandoned mines. Installing and maintaining bat gates is a costly endeavor and culverts are preferred for reasons such as low maintenance, longer life than a standard gate, and reduced chance of portal closure following installation. Due to its use in locations where standard bat gates are not a safe or practicable method, culvert bat gates provide an option to create and preserve more bat habitat than previously possible.

When deciding whether to gate or not, all practicable survey effort should be exercised to determine suitable gate design and location. If safe and practicable, future study of bats and gates should include pre-gate internal and external survey, which provides baseline data by which post-gate conditions may be compared. Costly long term monitoring and the responsibility of maintaining a non-essential bat gate may be avoided by conducting the appropriate research up front. The following are general management recommendations to consider when making a bat gate decision.

- Standard pre-gate surveys should be conducted at all potential gate portals.

  Site assessment is essential to determine the gate design most appropriate for a given portal, and pre-gate monitoring is strongly recommended before any gate project is undertaken to aid in the decision of whether a site should be gated or not (Fant et al. 2009). Bat activity may be monitored

through two general evaluations: internal surveys or external. Both general methods have their pros and cons which should be weighed when making management decisions however, external surveys may be the only acceptable survey method in Appalachian Region due to safety concerns. Internal surveys consist of looking for evidence of guano, staining, or observation of hibernating or roosting bats. Internal surveys may also measure aspects of the microclimate within a mine such as temperature, humidity, presence of gases, and airflow. External surveys may consist of counts of emerging bats, acoustic surveys, bat capture with nets or traps, thermal or infrared imagery, or drop cloths within an adit portal to collect guano. External surveys do not provide all information on the current or potential use of the abandoned mine by bats (Sherwin, Altenbach, and Waldien 2009). Internal surveys provide the most reliable information on past, present, or potential use of a mine (Sherwin, Altenbach, and Waldien 2009). Because of the inherit nature and instability of abandoned mines, external surveys are the only safe means to evaluate bat usage of an abandoned underground mine and internal surveys are not recommended for abandoned mine portals in the Appalachian Region. At a minimum, standard pre-gate surveys (e.g., Phase 1 - Initial Project Screening for Indiana bat) should be conducted at all proposed closure locations (USFWS 2019). Without appropriate surveys, all mines should be considered potential bat habitat (Vories and Throgmorton 2002; Brown and Berry 2002).

- Persons trained on gate design should conduct surveys, design site specific gates for each portal, and establish the goals of the gating project. Training should be developed and provided to staff involved in portal survey, and gate design, construction and monitoring.

  Poor gate planning, design, and implementation may result in detrimental effects to bats (Richter et al. 1993; Kerbo 2002). Training should be developed on external portal survey methods (e.g., Phase 1 - Initial Project Screening for Indiana bat) and provided for staff involved in gate design, construction, and monitoring. Persons trained on portal survey and gate design are knowledgeable of general bat biology and their relationship to the construction of a proper gate. Trained persons are knowledgeable in most current design specifications and engineering processes related to gate construction and are capable of designing a gate in a manner that will maintain the opening (Fant et al. 2009). Trained personnel should visit potential gate locations prior to gate design to understand all topographic, geologic and logistic conditions affecting gate design. Gate design plans should outline the objective of the gate, construction monitoring requirements, post construction monitoring for bat use or evidence of vandalism or portal collapse and adaptive management plans if alterations must be made post construction.

- The decision to gate abandoned mine portals should be evaluated on a landscape scale and collaboration across agencies to leverage existing data should occur. A geospatial database of gated locations should be created and maintained.

  Gating all potential sites on a landscape may be beneficial to species by providing a variety of microclimates and potential roost or hibernation sites in the case of entrances becoming closed (Tuttle and Stevenson 1978; Sherwin, Altenbach, and Waldien 2009; Tobin et al. 2018). A variety of features on a landscape (e.g., gated sites, or cavities in scree fields, outcrops or trees) may provide different roosting opportunities for bats. Since bats may not show fidelity to a particular roost, a variety of features could be helpful to sustain colonies and even populations of bats. The decision of whether to gate a site should include a landscape inventory of known caves and abandoned mines to evaluate proximity to existing known roosts and hibernacula.

A geospatial database of all existing gated locations and abandoned mine lands should be created and maintained in order to evaluate the proposed gates across the landscape. A working geospatial database could aid in the decision to simply close a portal due to an abundance of portals in an area or recognize unknown connectivity between mine workings across the landscape and decide to gate multiple portals. Without a working geospatial database it will continue to be unknown the effect of decisions to either gate or not gate a portal have across a landscape.

- The largest possible opening should be maintained at the gate site, all known portals at a site should be evaluated, and airflow should not be significantly altered.

Understanding airflow and its effect on microclimate within a coal mine is extremely difficult. There are a multitude of variables that are subject to change within an abandoned mine such as roof falls, unknown portals, and partial portal collapse which can dramatically alter airflow. Even variables as fine as rock texture and undulation (blockiness) of the ribs, sill, and back can have dramatic cumulative impacts on wind velocity, which in turn impacts substrate temperatures, turbulence, and the number of resultant micro-climates realized throughout a mine. Therefore, knowing what practices are best in terms of maintaining airflow, and what the effect to internal mine microclimates from gating are, will be generally unknown at any individual mine. Although the effects to airflow are unknown, the largest possible opening should be maintained when gating a portal. Study has shown that restricting the airflow may cause changes in the temperature, pressure and humidity levels deep within a cave or mine (Kennedy 2002b). These changes, although potentially small, may have great consequences on the cave/mine ecosystem (Currie 2000; Vories and Throgmorton 2002). To minimize changes in airflow when a culvert is used, the culvert should be sized as closely as possible as the original portal opening and concrete box culverts should be considered when appropriate (Currie 2000; Langdon 2002).

Gate placement should not impede bat flight, and gates with wider spacing between gate bars tend to be used more intensely than more narrowly spaced cross bars (Fant et al. 2009). It is widely hypothesized that smaller entrances may increase predation on bats, or more easily become obstructed by debris or vegetation. Obstructed entrances may limit the amount of available flight space or alter airflow which may make the mine microclimate unsuitable for use by bats (Tobin et al. 2018). Additionally, all known portals of a mine complex should be evaluated for an effect on airflow. Although a particular portal may not be an entry for bats, it may be important for maintaining the cave/mine airflow and therefore ecology (Sanders Environmental Inc. 2007).

Depending on the pre-closure portal condition, culverts may cause a greater change in airflow through the mine than a standard gate due to the resulting decrease in the cross-sectional area of the portal. However, it should be noted that in some cases the portal opening is actually increased from its original condition. In practice, the cross-sectional area of a site may increase with gate installation through the excavation of portal entries to install the gate. Upon initial inspection many portals are found to be nearly collapsed shut and some even documented as being completely collapsed (personal communication with WVDEP and OSM staff). During construction, portal areas are excavated to unearth the original portal dimensions. Although there is cross sectional area lost compared to actual original opening size, the culvert often provides the only option to protect the public and preserve the habitat despite the unstable geology.

- Alternative closure methods such as fencing should be considered at geologically unstable sites.

  Although most likely not practicable in the Appalachian Region, in areas where trespassing and vandalism are not chronic problems, a soft closure may be used to preserve the integrity of the cave/mine entrance and deter human visitation (Ludlow and Gore 2000; Buecher and Buecher 2002; Butchkoski et al. 2016a). Soft closures may be thought of as measures that discourage human use of a site and that do not reduce the area of the mine or cave opening (Buecher and Buecher 2002). A soft closure could restrict access to the site through the installation of gates across access roads leading to the portal. Fencing around a portal is an inexpensive option to deter human visitation of abandoned mine portals. Chain link fence at a height of 8 to 12' may be installed outside and around the perimeter of a portal with outward facing barbed wire above to deter vandals/trespassing (Vories and Throgmorton 2002). Fencing may be trenched into the ground or barbed wire installed along the base of the fence to further deter vandals. Fencing should be installed at sufficient distance from the portal to not interfere with bat flyways. Fencing should also not be installed inside a portal. It is important that both of these guidelines be followed so that access to the portal isn't impeded, and the portal opening remains unaltered, thus minimizing the effect on bat behavior and microclimate of the mine.

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