MONITORING THE EFFECTIVENESS OF BAT COMPATIBLE MINE GATES

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Abstract

Abandoned underground mine workings pose serious threats to human safety. Many agencies have installed wildlife-passable gates at mine openings in an effort to mitigate these losses. Long-term monitoring studies have been initiated to determine if gates affect population numbers or alter behavior of animals using mines. Designing an effective monitoring program requires identification of the questions to be addressed, the scale, and the strengths and limitations of the methodologies used. This paper provides some recommendations for designing an external bat gate monitoring study, including a list of assumptions to be considered and questions to be addressed prior to selecting a methodology. Discussion of some of the more commonly used monitoring methodologies is also provided as well as advantages and disadvantages associated with each. Commonly used methodologies for biological monitoring include: exit counts, alone or enhanced using lights or night vision equipment; infrared event counters; video imaging; and acoustic detectors. Other methodologies being tested include thermal infrared video imaging, radar, and electronic transponders.

Introduction

Abandoned underground mine workings pose serious threats to human safety. To protect the public from the hazards of abandoned mines, public land managers have implemented large-scale closure efforts, often at significant expense. The most economically feasible mine closure methods include blasting, plugging, backfilling, and other permanent solutions.

Studies have shown that numerous wildlife species use these artificially created habitats including bats, mice, woodrats, skunks, ringtail cats, mountain lions, and a variety of birds and reptiles (Brown *et al.* 1995). Eighty percent of the mines in the Western U.S. show some evidence of bat activity (Tuttle and Taylor 1998). Permanent abandoned mine closure methods have not only resulted in destruction of roosting habitat but have also caused direct mortality of bats by entombing them within the sealed mine (Brown 1995, Brown and Berry 1991, Altenbach and Pierson 1995).

Many agencies have installed wildlife-passable gates at mine openings to mitigate the loss of animals and their habitat resulting from permanent closure. Gates allow animals to pass through openings too small for most humans, while maintaining air flow patterns crucial for internal habitat conditions. Unfortunately, many early gate designs impeded bats in flight, allowing predators to take bats easily (Tuttle 1977, Altenbach and Pierson 1995, Currie 2001). In some areas, bats have abandoned historic roosting areas despite the addition of bat compatible gates.

Currie (2001) suggests that bat compatible gates can be considered successful if the structure keeps people out, does not adversely affect mine microclimate, and the bat population remains stable or increases. For the most part, gates have effectively excluded 95 percent of the public from the dangers of abandoned underground mine workings (Currie 2001). However, few long-term monitoring studies have been conducted to determine if the gates impact bats or their behavior. To date, most studies have relied upon poor or biased study designs and failed to consider issues of scale (Altenbach et al., 2001; Sherwin et al., 2001).

Biological monitoring is important in identifying adverse affects to bats resulting from gate installation. Monitoring study results have been used to provide feedback for future modifications in gate design, select the most appropriate closure method at similar sites, predict bat response to gates, and to develop an index of bat population trends. In many cases, the decision to gate rather than fill a mine was based on the assumption that a resident bat population used the mine. Similarly, gates have been installed where bat colonies were not previously reported on the assumption that bats would locate and occupy the available habitat. Individuals and agencies financing bat gate installations want to know if the additional expense of gating is justified.

However, making accurate and meaningful determinations of whether a bat colony or population is increasing in number can be problematic (O:Shea and Bogan 2000). Bats form colonies of different sex and age compositions throughout their annual cycle (Kunz and Kurta 1988, Altringham 1996, O:Shea and Bogan 2000). Colonies may form specifically for reproductive activities such as parturition, rearing of young, courtship, or mating. In addition, colonies may form as resting aggregations during nightly foraging activities or migration (Kunz and Kurta 1988, Altringham 1996). Some species switch from one roost to another every few days during the warm season (Kunz 1988, Altringham 1996, Rabe et al. 1998, Herder and Jackson 2000, O:Shea and Bogan 2000). Individual bats may leave roosts through different portals on successive nights, or may remain in the roost if environmental conditions outside are inhospitable (Kunz and Kurta 1988, Herder and Jackson 2000). Very little is known of the basic natural history, distribution, and roosting preferences for many species (Kunz 1988, Herder and Jackson 2000, O:Shea and Bogan 2000). As a result, estimating the number of bats using a particular mine site is a complex problem that may not be resolvable by counting bats as they exit.

This paper provides some recommendations for designing an external bat gate monitoring study, including a list of assumptions to be considered and questions to be addressed prior to selecting a methodology. Discussion of some of the more commonly used monitoring methodologies is also provided as well as advantages and disadvantages associated with each. These recommendations are offered primarily for warm season monitoring studies following gate installation. However, most of the methods are easily adapted to pre-gating situations at any time of year.

Considerations for Bat Gate Monitoring Studies

Many considerations are required in designing a bat gate monitoring study. In reviewing documentation of previous monitoring studies, several issues consistently arise associated with study design. These include:

- $ Lack of an adequate or well defined study plan including purpose, objectives, and assumptions
- $ Lack of pre-gating data as a baseline for comparison
- $ Changing study design or data collection methods between pre- and post-gating
- $ Reliance upon anecdotal observations rather than quantifiable measures
- $ Making invalid study assumptions
- $ Failing to address spatial or temporal issues
- $ Selecting methods that are not sensitive enough to detect changes in roost numbers
- $ Overestimating the significance of changes in bat numbers, and
- $ Not publishing information where it is accessible to others

The following are offered as suggestions to consider in designing a monitoring study and determining which methodology is best suited to the task. This is by no means an exhaustive review. Readers who intend to design a bat gate monitoring study are referred to text books on study design and sampling theory, and encouraged to consult with a statistician.

EXTERNAL VS. INTERNAL SURVEYS

Where possible external surveys are preferable due to the inherent dangers associated with entering abandoned mines and the potential for compromising the integrity of the closure. However, external surveys are limited by the inability to determine if all of the animals have exited. Pre-closure surveys should be conducted for at least one year, including both warm and cold season checks, to establish baseline use levels. For a more complete discussion of external versus internal surveys see Altenbach et al. (2001).

PRELIMINARY SITE EVALUATION

Several initial site visits may be necessary to determine baseline conditions and select the most appropriate method for monitoring. Altenbach et al. (2001) provide a thorough discussion of the elements of a preliminary site evaluation. The highest priority should be location of any and all human safety hazards present at the mine portal to minimize danger to observers. Hazardous areas should be flagged during daylight hours so that they can be avoided.

Determine the most appropriate location for counting bats during out flights. If possible, a determination of which bat species are using a particular mine should be made during the preliminary site evaluation. Specific habitat needs and adaptability of the species to gates is known for some species and could be extremely useful in determining the best approach for monitoring. A discussion of which North American bats use mines and the roost attributes they prefer is provided in Tuttle and Taylor (1998).

Preliminary site evaluation is the first opportunity to address issues of scale. Spatial scale issues include identifying suitable roost locations within the local area, if possible. The size of the area considered will vary by bat species, but a 25 km (15.5 mi) radius should provide an adequate range for most small to medium sized insectivorous bats. Clearly, increasing the size of the study area increases the scope and complexity of the effort involved. However, failure to consider roost switching to alternate sites may lead to erroneous conclusions about the effectiveness of the gate. An increase in colony size at a particular mine may be an indication that previously dispersed bats are using a roost due to the increased protection afforded by the gate. However, it is equally likely that an increase in immigration is a result of closure or loss of a nearby roost.

Similarly, all potential exit points should be located for mines with multiple openings. Multiple exits will require additional equipment, labor, and time to effectively monitor. Counting bats at a gated mine portal is of little value if some unknown proportion of the colony is exiting through another unmonitored opening.

The same concerns exist for temporal scale issues. A determination of the time of year the site is used and the type of roost is essential in developing an effective monitoring study. Exit surveys at the portal are of limited value if the site is only used as a hibernacula. Maternity colonies often relocate to a different roost once the young have learned to fly. Subsequent moves may occur with the onset of breeding activities or in preparation for migration or hibernation. As a result, observers may conclude that a gate has had an adverse affect on the bat colony. In addition, mines may be used by bats as day roosts, night roosts, or both. The methodology chosen to monitor a day roost may be different from that chosen for a night roost.

A hypothetical ideal site would include a solitary gated mine with one portal, far enough away from other roosts that roost switching could be considered rare or non-existent. Unfortunately, solitary mines with closed bat populations such as this are not common.

PREPARE A STUDY PLAN

The study plan should clearly identify the purpose of the monitoring study, define and document study objectives, and identify assumptions. The study plan should also document what parameters are to be measured, the scope or extent of the study, how spatial and temporal scale issues are addressed, timing and duration of the study, the choice of method(s) used, and how success will be determined.

One of the most important issues to be addressed in designing a bat gate monitoring study is establishing what questions the study will attempt to answer. Questions most commonly posed by such studies include:

$ How many bats use the site?
$ What time of year do bats use the site?
$ What species of bats use the site?
$ Has gating led to an increase or decrease in the number of bats using the site?
$ How has or will gating affect bat behavior?
$ Is there movement of animals between this and other adjacent areas?
$ What parameters will be used to define gate success?
$ Does the study need to use a method that is repeatable?
$ How much time, money, and effort is available to answer these questions?

A list of the assumptions made is crucial to grasping the significance of the data collected. Common assumptions for bat gate monitoring studies include:

- $ Changes in numbers counted exiting the roost mean that the colony or population size has changed
- $ The methods chosen are sensitive enough to detect changes in colony or population size
- $ The methods chosen do not appreciably affect the bats or cause them to alter behavior
- $ All possible exit locations are monitored, and
- $ All bats exit every night

STUDY DESIGN

Bat species vary greatly in the way they select and use habitat, both within and outside of mines. These interspecific differences in roost requirements, breeding behavior, foraging strategy, echolocation, and flight morphology lead to differences in how bats use and behave in their environment. This in turn affects our ability to observe and count them. No technique currently exists to measure the absolute abundance of bats, except in extremely localized areas such as single roosts (Thomas and LaVal 1988). It is therefore impractical, and perhaps impossible, to obtain accurate absolute counts of bats at either the population or habitat level.

A number of factors influence the design and effectiveness of gate monitoring studies, including:

- $ Warm season monitoring will be limited in most cases to 5-6 months of the year when bats are present and active
- $ Cool season or hibernacula monitoring will be limited to two short periods of intensive monitoring during the fall and spring to establish the onset and termination of hibernation
- $ Only a small number of closely situated mine gates can be effectively attended, depending on the availability of personnel and equipment
- $ Repetition of sampling effort is desirable to increase precision. However, not all sampling periods will be suitable due to the constraints of weather
- $ Bat activity varies with ambient air temperature, humidity, moon phase, and availability of insect prey species, all of which change throughout the season

These factors require that an adequate number of observations (sample size) be made. Repeated observations at the same site(s) under the same or similar environmental conditions are necessary to produce an accurate count (Vonhoff 2002). The number of observations required for statistical significance in making relative abundance estimates will depend on the type of roost monitored, the methods employed, and the ability to hold these variables constant. Consult with a statistician to determine the optimum number of observations required for statistical significance.

Monitoring Methods

Because some members of a colony may remain within the roost during reproductive activities (Bogan 2000) or during periods of inclement weather (Thomas and LaVal 1988), nightly maximum counts

should be considered an estimate of relative abundance. No one technique will be ideally suited to detect and count all bat species in all locations.
Among the most common tools available for monitoring bat gates are exit counts, capture, acoustic surveys, infrared event counters, infrared video, and various combinations of these methods. Each method described has benefits and drawbacks associated with their use. There are also a variety of newer technologies available that are currently too expensive for most applications. However, the price of most of these technologies is expected to drop in the future. See Rainey (1995) for additional discussion of some of these methods.

The choice of monitoring method used will depend upon the physical layout of the site as determined in the preliminary site evaluation, the number of alternate roost sites within the study area, the species of bat present, the type of roost (whether day or night, maternity, bachelor, hibernacula, etc.), the season of use, and the manpower and financial capabilities of the observers. If time and funding allow, it is best to combine several methods to obtain presence/not detected and relative abundance data.

PORTAL SURVEYS/EXIT COUNTS

The most common technique used in counting bats at mine openings are portal surveys, also called exit r emergence counts. During a portal survey, one or more observers position themselves at fixed stations, silhouetting bats against the sky and count the animals as they exit. Portal surveys are typically begin at or before dusk and may continue until the out flight is complete or longer. Observers commonly using tally (lap) counters to record the number of exiting bats. Typically, each observer holds two tally counters, recording out flights with one and in flights with the other. In flights are subtracted from out flights after the survey is complete.

It is usually desirable to enhance visibility with red filtered lights or night vision equipment. White lights should be avoided as they may affect bat behavior. Observers should be positioned perpendicular to, but well outside of the flight path of bats as they exit the roost, preferably in front of a solid stationary object such as a rock wall. Observers should avoid sitting in the open where they would be silhouetted against the sky. Observer comfort is important as fatigue can introduce bias to the study results. For a more detailed description of portal surveys, readers are referred to Thomas and LaVal (1988), Navo (1995), and Rainey (1995).

Portal surveys are simple and relatively inexpensive, particularly where natural or red filtered lights are used. Night vision equipment increases the reliability of observations. Volunteer labor can be used to reduce costs (see Navo et al., 1995). Where sufficient personnel are available it may be desirable to have multiple observers make independent (double blind) counts to verify survey results. Observers are usually able to determine whether a bat passing through a gate is coming into or out of the mine. Experienced observers may be able to distinguish species visually. Portal surveys may be used pre- or post-gating.

Among the drawbacks to portal surveys is that they tend to be time and labor intensive and may have highly variable results. The number of exiting bats may vary with environmental conditions such as wind, rain, humidity, and moon phase. Bats may also remain in the roost during peak breeding activities.

Portal surveys provide no reliable method for determining species identification. No permanent record is available of visual observations other than the tally counters. Observers may loose count or be overwhelmed by out flights in excess of more than a few dozen at one time. Swirling or repeated out and in flights may confuse observers. Observer fatigue may result in missed bats or confusion between in flights and out flights. As equipment and personnel increase, so does the cost associated with portal surveys. Quality night vision equipment (generation 3 or better) start at over $1,000 U.S. for monoculars. Hands-free headset units are $3,000 U.S. or more. Observer presence may disturb bats, particularly if observers are noisy, using lights, moving about, or are positioned in less than ideal locations. Bats may also react to the presence of observers, possibly biasing counts.

CAPTURE

Capturing bats is the most common method for establishing which species are present in the study area. With bats in hand positive species identifications are possible. Additional information may also be obtained such as sex, age, and reproductive status of those species captured. The two most common devices used for bat capture are mist nets and harp traps. For a complete description of the use of these and other capture methods see Kunz and Kurta (1988).

$ **Mist Nets**. Mist nets vary in size, typically measuring from 6 to 36 m in length and 2 - 3 m in height. Mist nets used for capturing bats typically are made of 50 or 70 denier/2 ply nylon with a mesh size of 36 mm. The nets are suspended from poles directly in the flight path of exiting bats. The bats fly into the mesh and becoming entangled in one of three or four baggy shelf panels. Mist nets typically cost between $50 and $150 U.S. depending upon size. Import restrictions sometimes limit the availability of mist nets.

$ **Harp Traps**. Harp traps generally consist of two rectangular frames, with vertical strands of monofilament fishing line every 2.5 cm. The two frames are spaced 7 - 10 cm apart, face to face, with the monofilament lines on each frame offsetting each other. A collection bag is suspended below the frames. Bats generally pass through the first set of lines, but are unable to negotiate the offset between the frames and fall into the holding bag below. Harp traps typically cost between $400 and $1,500 U.S. Several references provide plans for building harp traps (Tuttle 1974, Tidemann and Woodside 1978).

Catching bats in mist nets and harp traps depends on careful placement of these capture devices. Wind, rain, bright moon, and other environmental factors may affect capture success. Duplicating exact net or trap placement is relatively easy at mine openings, though success may decrease if nets or traps are used in the same location on consecutive nights (Kunz and Brock 1975). Once placed, mist nets should be closely monitored. Harp traps do not require constant tending and so allow a larger number of mine portals to be surveyed during one sample period. Care should be taken to avoid capturing more bats than observers are prepared to handle.

Most capture devices are relatively inexpensive, highly portable and easy to use and set up. Mist nets provide a large collecting surface. Capturing animals provides a method for determining the species using a particular site, assuming the net only captures species exiting the mine and those animals are correctly identified. Using a net set at the mine portal, it is possible to determine whether the bat was entering or exiting the site. Capture techniques are useful in both pre- and post-gating situations. Capturing bats is also the necessary precursor to application of radio telemetry or light tags. There are numerous drawbacks to using capture techniques at mine openings. Among these, disturbance to the bats during capture and handling is the most troublesome. Bats may be killed as a result of excessive handling. Those that survive may relocate to another roost, sometimes abandoning their young in the process. All observers involved in capturing bats should be trained in use of the specific capture devices and in techniques for handling bats without injuring the animals. Observers handling bats should also receive rabies pre-exposure vaccinations. In order to assure proper identification of species in hand, observers should be trained in using taxonomic keys. Despite training, the potential for misidentification of bat species is high as distinguishing characteristics for some species are difficult to locate and identify.

Because of differences in their behavior, morphology, and/or flight patterns, some bat species are not easily captured (Vonhoff 2002). As a result, most capture techniques are biased towards the more easily captured species. Some species are adept at avoiding capture in mist nets or harp traps. Younger age class animals are more susceptible to capture than older age classes, leading observers to overestimate the proportion of juveniles in the colony.

Mist nets are time and labor intensive to use. Harp traps are expensive and have a relatively small capture area compared to mist nets. Neither method provides an indication of the proportion of the colony captured (or missed). Both capture methods are readily detected by bats and likely alter the behavior of the animals.

ACOUSTIC MONITORING

Bats rely on vocalizations for communication and orientation when orienting, commuting, and foraging (Fenton 1985, Altringham 1996). By emitting a series of discrete calls and listening for returning echoes, bats are able to navigate through their environment and locate prey items (Fenton 1970, Thomas and West 1989). Bats searching for prey emit a characteristic ›feeding buzz.: Because sounds produced are generally $\geq$ 20 kHz and are outside of the range of human hearing, an ultrasonic bat detector is required to monitor bat vocalizations.

Acoustic surveys are conducted by using one of the commercially available ultrasonic detectors to record and identify bat vocalizations. Bat detectors come in a wide variety of forms, but they can be distinguished on the basis of the circuitry used to transform the incoming signal; heterodyne, frequency division, and time-expansion (Pettersson 1993, Vonhoff 2002).

Heterodyne circuitry is used in so called tunable detectors. Observers can scan particular frequency ranges and sample for bat species that employ calls with different frequency components by simply tuning the detector. However, neither the duration nor the absolute frequency of the original signal is present in heterodyne signals, and thus is not suitable for further spectral analysis. These detectors are useful for measuring general bat activity where species identification is not required. Commonly used heterodyne detectors include the Mini, Mini-2, and Mini-3 detectors from UltraSound Advice (formerly QMC), the D100, D200, and D220 detectors from Pettersson Electronik AB, the BatBox III from

Stag Electronics, the Mk.2 detector from Magenta Electronics, and the SBR 1200 and 2000 made by Skye Instruments. Prices generally range from $150 to $250 U.S.

With frequency division detectors, the incoming signal is passed through a zero-crossing circuitry that isolates the dominant or loudest harmonic, divides the frequency by a user specified value, and provides output within the human audible range. The signal may then be recorded onto analog or digital tapes, or monitored in real-time using computer software. Information regarding the time and frequency characteristics of the dominant frequency are retained. This broadband system allows observers to monitor the entire range of frequencies simultaneously. This permits a greater sampling effort. Commercially available frequency division detectors include: S200 and U30 from UltraSound Advice, the D230, D940, and D980 units from Pettersson, and the Anabat II system made by Titley Electronics. Frequency division detectors range in cost from $350 to $950 U.S.

Time expansion detectors capture the incoming signal, including harmonics. The signal may then be recorded onto analog or digital tapes, or monitored in real-time using computer software. Commercial time-expansion detectors include the Portable UltraSound Processor (PUSP) from UltraSound Advice and the D240, D240x, D980 models from Pettersson. The higher information content of these time-expansion systems comes at a high cost. High-speed tape recorders and detectors with time-expansion systems typically range in cost from $1,000 - $6,000 U.S.

Advantages of conducting acoustic surveys include the potential for conducting remote, unmanned surveys, allowing automatic monitoring of bat calls while freeing the observer to perform other tasks. The output of heterodyne, countdown, and time-expansion systems may be recorded to analog compact cassette recorders, digital DAT, CD, or DVD recorders, or directly onto a computer using specialized software. This provides a permanent data record with a time/date stamp. These stored files are available for review at a more convenient time. One of the most debated issues with acoustic surveys is the capability of different units to produce a file that can be analyzed to determine the species of bat making the vocalization. While this is an acquired talent that requires extensive training and experience, it is possible to identify certain species and species. This is particularly true if a reference collection is established for the site from bats captured and released. Extensive discussions of this subject are provided by Pettersson 1993, Rainey 1995, Hayes and Hounihan 1994, Betts 1998, Weller et al. 1998, Barclay 1999, O=Farrell et al. 1999a, O=Farrell et al. 1999b, Vonhoff 2002). Call libraries are available for additional post-collection analysis (see http://sevilleta.unm.edu/~wgannon/batcall).

The cost of ultrasonic detectors and associated hardware and software can be a disadvantage in using these systems. No count data or estimate of abundance is possible from acoustic data. The observer cannot tell the difference between one bat making twenty separate calls and twenty bats making one call each. The equipment has a finite range, typically about 30 feet, for detecting calls. Bats that are closer will be picked up before, and sometimes at the exclusion, of those farther away. Bats that echolocate at higher amplitude will drown out bats that are vocalizing quietly. The detector cannot distinguish whether a bat was flying in or out of a particular mine gate, or if the bat was simply passing by and was not associated with the mine.

There is a steep learning curve associated with both operating the equipment and learning to identify bats to species. Some bat species which are readily identifiable in hand are difficult or impossible to separate using acoustic surveys. Most call libraries are composed of echolocation sounds made during foraging. But bats produce a variety of social and navigational sounds as well (Fenton 1970, Fenton 1985, Thomas and West 1989, Altringham 1996). At present, there are no keys to social sounds of bats. It is likely that bats use navigational rather than foraging signals while navigating through the bars of a bat gate. Foraging signals are probably not used until the bat is well clear of the gate structure. Bat calls detected near mine openings cannot be verified as coming from bats using the mine.

ELECTRONIC EVENT COUNTERS

Electronic event counters consist of a photo-electric beam, typically in the infrared spectrum, coupled with a time/event data logger to count bats (Kucera and Barrett 1993, Rainey 1995). These are essentially the same units that are used in retail stores to signal someone has entered. A wide variety of models are available for different applications. Passive infrared units emit a broad beam that is activated by both temperature and motion. Bats moving through the beam with a surface body temperature at least one degree above ambient temperature would be counted with a time/date stamp. Passive units may also be used to trigger a video camera. These units are effective at distances of 100 feet or more for larger animals. With bats, the useful distance is substantially reduced. However, mine openings typically offer restricted passageways where a passive unit might be effective.

Active infrared monitoring systems use a transmitter and receiver unit to transmit a narrow beam. Bats passing through the beam are counted with a time/date stamp. These units are typically oriented vertically just inside the mine gate. Larger gates may require more units. The sensitivity of these units may be adjusted to minimize the reset time between events. Infrared beams may be transmitted as far as 45 m (150 feet). The TM1550 developed by TrailMaster is specifically designed for monitoring bats and retails for approximately $360 U.S. Those with aptitude in electronics may wish to construct their own infrared photo-electric beams.

Active infrared event counters can be an effective tool for counting bats entering and exiting mines. Infrared event counter systems may be deployed in large numbers in remote settings, such as might be used in pre-gating situations. Battery life is typically three weeks or more depending upon the unit. Commercial units provide a time/date stamp, and have user selectable sensitivity and reset times. These units have rapid download and retrieval capabilities. Many commercial systems have an alarm or trigger mechanism, allowing the observer to activate a camera or other device when the beam is broken.

As with other methods for monitoring, electronic event counters have weaknesses which may bias count estimates. Commercial units cover a relatively small area and may be difficult to align. Sensitivity settings may not be appropriate for situation at a particular site. It is not possible to distinguish in flights from out flights using these units (though some manufacturers have multiple beam systems). Species identification is not possible with electronic event counters alone.

Electronic event counters typically underestimate numbers when bats overwhelm the counter by repeatedly breaking the infrared beam before the unit can reset. Underestimates also result from bats avoiding the photo-electric beam. Electronic event counters are less effective with large colony sizes where hundreds of bats may exit at one time. Conversely, event counters overestimate the number of bats present when a single individual repeatedly triggers the counter, such as by circling the beam. The author has made numerous observations of bats circling the overhead receivers. These bats may be hearing ultrasonic noises from the event counters, may detect the infrared light, or may be reacting to the presence of a foreign object in an otherwise familiar environment. Bats may require an acclimation period where they require time to be accustomed to the presence of the device in their environment. These units will work either for pre- or post-gating surveys. However, without the gate in place, a restricted opening is required to ensure that bats will pass through rather than around the beam. In addition, the units are accessible and attractive to vandals.

INFRARED VIDEO

$ **Camcorders.** A wide variety of video camcorders are available commercially with the capability of taking still or video images in low light situations using infrared illumination. Digital or analog images are stored on tape media within the camcorder housing or may be transferred to a more conveniently located monitor/recorder system via audio/video cabling. Camcorders are widely available with many models and features to choose from. Most newer units offer digital recording capabilities and titling capabilities including time/date stamps. The cost of these units varies from $350 to $2,000 U.S. with most units in the $600 - $900 range. Nightshot camcorders are made by Sony, Sanyo, Phillips, Jensen, Toshiba, and a number of other manufacturers. Image quality ranges from fair to excellent depending on cost. Supplemental infrared lighting is also available. More sophisticated units offer remote control zoom, tilt, and pan. These camcorders should be mounted on a tripod. As a result, they often end up within the flight path of the bats as they exit, posing a potential disturbance bias. In addition, tape and battery life limitations may require an observer to change tapes and/or batteries every few hours, causing additional disturbance to the bats.

$ **Spy Cams**. A wide array of Aspy cams@ are available commercially including those known as bullet, box, pinhole, and lipstick cameras. These units consist of a small camera lens with cables attached for audio and video output and either AC or 12V DC power. Spy cams do not have recording capabilities. The signal must be transferred offsite to a monitor/recorder system. Spy cams typically do not include an audio output. Spy cams typically cost between $60 and $350 U.S. depending upon the size, shape, and configuration of the camera, the maximum resolution, whether color or black and white, and the number of infrared LEDs provided. Monitors can be as inexpensive as $50. The popularity of recreational vehicles has made DC powered TV/VCR combination units readily available for less than $200. With the addition of a quad or multiplexer unit, signals from numerous cameras can be viewed simultaneously in split screen format or one camera at a time.

Video cameras provide a means for verifying the accuracy of events recorded on infrared event counter and allow observers to monitor bats and their behavior as they fly through the gate. Video tape is a permanent storage method for recording data that allows unlimited review time with pause, rewind, and play back features. The smaller spy cams are ideal for less intrusive camera placement. Spy cams can be mounted on a small tripods and positioned on the ground, behind rocks, or on the rib of the mine for camouflage. Because the recorder is located away from the mine portal, the observer can change tapes without disturbing the camera setup. Observers may control what video is recorded and what is not by viewing the monitor(s). Wireless transmitters are also available to send audio and video signals up to 400m from the site to reduce disturbance.

Camcorders can be expensive and bulky. Spy cams are comparatively less expensive, are smaller, and more easily camouflaged. Spy cams require additional equipment, and connections that may fail. Camcorders offer more options for trigger by remote devices, but startup time decreases their usefulness. Power up time for camcorders is generally 3-5 seconds, by which time most bats would likely have exited the field of view. Setting the camcorders in pause mode would substantially reduce the power up time, but would require almost as much battery life as recording mode. In addition, most camcorders will automatically power-down after a specified period of inactivity in pause mode. Many Nightshot camcorders offer a video out feature that allows you to cable the signal to another monitor/recorder setup. However, this makes the camcorder little more than a bulky, expensive, high-resolution spy cam.

Limitations of video systems include short tape and battery life and low resolution. Most video tapes are limited to two hours, though this can be extended to six on most systems by switching to a lower resolution, extended play mode. Most Nightshot camcorders offer optional extended life batteries. Battery life can also be extended by cabling a DC power source to a more remote battery. This increases setup time and the possibility of problems, but is desirable because it minimizes the effect of observer presence on exiting bats. Spy cams require far less power and can be run from 12V gel cell batteries or AC power. The availability of AC power at the site greatly increases setup options.

Another limitation of video systems is the field of view. Once a bat has left the camera=s field of view, subsequent sightings should be considered different bats unless some unique identification is available. This problem does not occur with portal surveys as observers are free to track individuals in flight. Lighting can also be an issue. Experiment with placement of infrared lighting to prevent washed out or dimly let areas of interest.

Video systems all require an extensive analysis period where observers are required to review tapes to extract pertinent data. Review time is typically at least twice the length of the recordings, and often considerably more. One method for reducing tape review and analysis time requires an observer watch the monitor(s) and take notes in real time. Events of interest can be noted on the data sheets or with a time-event recorder. During review, the list of events can be used to identify what segments of the tape will require additional analysis.

COMBINING METHODOLOGIES

While none of the methods described provides an ideal solution for bat gate monitoring, most methods may be combined to take advantage of the strengths of each. For example, electronic event counters coupled with infrared video provide double counts which can be used to verify the accuracy of the methods used. Portal surveys may be conducted from a distance using spy cams to limit observer effects and disturbance. Using multiple cameras with overlapping fields of view should provide the most effective coverage.

OTHER PROMISING METHODOLOGIES

Thermal infrared camcorders are now available commercially. These cameras record heat emanating from any object with a body temperature greater than the surrounding environment. Output from the camera appears as isothermic lines, each with its own color. Unfortunately, these devices are very expensive, with costs for even the lowest priced thermal imaging camera beginning at $13,000 U.S.

Passive transponder (PIT) tags are a tiny implantable device that must be attached to or inserted under the skin of the bat. Each tag has a unique identification code that is read by circular reader similar to a bar code wand. As the bat passes through the reader, the PIT tag is identified by the reader and recorded. PIT tags allow for positive identification of individual bats. Using PIT tags, observers should be able to determine when bats use a particular site from year to year. However, readers may not reliably detect bats on every pass, particularly if the bat is oriented in such a way as to block the reader with its body. At present, the largest affordable readers are approximately 0.3m in diameter. In the future, readers may be designed so as to be mounted on a bat compatible gate.

A variety of software programs have been and are being developed to enhance counts made from video applications. These software programs are available commercially, but can be very expensive (see http://www.noldus.com). Several universities are also in the process of developing computer software that will make automated counts of bat colonies from video tape.

Summary

Designing an effective monitoring program requires identification of the questions to be addressed, assumptions made, spatial and temporal scale, and the strengths and limitations of the methodologies used. Conduct pre-gate surveys where possible to document baseline conditions. Where possible, external surveys are preferable due to the inherent dangers associated with entering abandoned mines and the potential for compromising the integrity of the closure. Pre-closure surveys should be conducted for at least one year, including both warm and cold season checks, to establish baseline use levels.

Commonly used methodologies for biological monitoring include: exit counts, alone or enhanced using lights or night vision equipment; infrared event counters; video imaging; and acoustic detectors. Other methodologies being tested include thermal infrared video imaging, radar, and electronic transponders. Care should be taken to select a method with minimal disturbance to the animals being monitored. Table 1 includes a summary of advantages and disadvantages of using each of the methods discussed.

Portal surveys can be among the most cost effective means for biological monitoring, particularly if volunteers are available. However, underestimates may occur when animals are not observed or counted due to inadequate visibility, rapid exit of large numbers of animals, or observer fatigue. Under estimates may also result when observer presence disturbs exiting animals and/or causes a change of behavior. Even when the number of animals exiting is precisely counted, observers have no way of verifying the accuracy of counts, of knowing if all animals present exited the site, or of determining which species were present.

Capturing bats as they exit is the most effective method for identifying species. However, this method can cause a great deal of stress to the bats and may lead to roost abandonment and mortality.

Acoustic surveys provide a means for identifying species and may be used in remote, unmanned situations. However, identifying species can be problematic and requires training and experience. Some bats may not vocalize until they are away from the mine portal. It may not be possible to discriminate between vocalizations of bats using the mine and those of passing bats.

Battery-powered infrared event counters are effective for counting animals entering and exiting mines. However, event counters may underestimate numbers when multiple animals trigger the device before it has time to reset or when individuals avoided the beam entirely. Conversely, event counters may overestimate numbers when a single individual repeatedly triggers the device, such as when bats circle the infrared beam. Remote devices are subject to vandalism, do not distinguish between out flights and in flights, and do not distinguish one species from another.

Infrared video cameras may be used to verify the accuracy of event counters and monitor animal behavior at the site. In some cases in may be possible to permanently mount infrared cameras within the mine to monitor roosts. Limitations of video systems include short tape and battery life and low resolution. Visual data stored on video tape serves as a permanent record which may be retrieved, analyzed, and edited at any time. However, reviewing video data can be very time-intensive without the use of costly electronic video editing tools. As with event counters, equipment left at the site may be subject to vandalism.

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Table 1. Comparison of Advantages and Disadvantages of Gate Monitoring Methods

	Portal Survey	**Capture**	**Acoustic**	**Event Counter**	**IR Video**
Disturb bats or change behavior	May	Yes	No	May	May
Species Identification	No	Yes	May	No	No
Reliability of Estimates	High	No Estimate	No Estimate	Mid-High	Mid-High
Unmanned Setup Possible	No	No	Yes	Yes	Yes
Distinguish In flights from Out flights	Yes	Yes	No	No	Yes
Use Volunteers	Yes	Yes	No	Yes	Yes
Cost	Low	Low-Mid	Mid	Mid	Mid-High
Other Considerations	Night vision equipment improves survey, adds to cost	Reliability of species identification depends on training	Reliability of species identification depends on training and equipment	Over estimates and under estimates possible	Placement, lighting, battery and tape life issues

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