Digital Photography Improves Consistency and Accuracy of Bat Counts in Hibernacula

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ABSTRACT The size and distribution of measurement errors associated with major techniques for estimating numbers of hibernating bats are unstudied, although this is the principle method of enumerating several endangered bat species. However, decisions concerning the listing status of a species under the Endangered Species Act require consistent and accurate estimation of population size and trends. Recent advances in digital photography have improved the ability to produce a quantitative record of the numbers of bats in hibernacula. We surveyed clusters of Indiana bats in a hibernaculum and compared results from counts of digital photographs of clusters to results from 4 variations of visual estimation. We counted bats in photographs using Geographic Information System digitization over the photograph. Total counts from 2 sets of photographs varied by <1.5%. Nonphotographic estimation techniques varied from 76% to 142% of counts from photographs for clusters for which estimation (rather than counting) was used. Where feasible, photography can improve status and trend information for species of concern, permitting more timely and specific management actions.

KEY WORDS error detection, Indiana bat, interobserver variability, photography, population estimation, simulation.

Sources of error in wildlife population estimation have been the subject of extensive research both to quantify and to reduce potential error (Thompson et al. 1998; Buckland et al. 2001, 2004; Thompson 2004). Studies to quantify observer error, differences among observers, and differences among techniques have a relatively long history in ornithological research (e.g., Ralph and Scott 1981). In other species, however, efforts to describe errors related to observers and techniques are less consistent.

Indiana bats (Myotis sodalis) are federally listed as endangered and hibernate in caves and mines, primarily from Arkansas to Virginia, USA, in the south and from Illinois to Vermont, USA in the north (Clawson 2002). Indiana bats travel up to hundreds of kilometers from breeding areas (Kurta and Murray 2002) to overwinter in a relatively few caves and mines, where they often hibernate in dense clusters (Clawson et al. 1980); large clusters comprise thousands, occasionally tens of thousands, of bats. By surveying these sites, researchers can monitor large proportions of the overall population with relatively little effort.

The entry of a survey team into a hibernaculum for more than a brief time (<1 hr) rouses bats, forcing them to use energy from fat stores that must last through the winter (see Thomas et al. 1990). Because of the risks associated with unnecessary arousal of bats, the United States Fish and Wildlife Service (USFWS) survey protocol for Indiana bats at hibernacula encourages speed and restricts entry into individual hibernacula to one entry every 2 years. As a result, opportunities for research on any aspect of these survey techniques have been limited, despite an acknowledged need for such research (O’Shea and Bogan 2003). A USFWS workshop on risk assessment for the Indiana bat (USFWS 2006) and subsequent work to update the Indiana bat recovery plan (USFWS 2007) provided the impetus for a species-specific comparison of enumeration techniques using 5 teams of experienced observers and 5 approaches: photography and 4 variations of visual estimation. Our goals were 1) to determine the consistency of photography as an enumeration technique and to compare visual-estimation results to photographic results, and 2) to consider the implications of our findings for the methodology of future surveys of bat species that use hibernacula.

STUDY AREA

The study area, Magazine Mine, was a microcrystalline silica deposit in Alexandria County, southern Illinois, with several mine complexes (Kath 2002). The mines were easy to access, had regular surfaces that would be equally convenient for
different survey techniques, and were under friendly, private ownership. In addition, there were excavated areas traditionally used by Indiana bats and separate areas that traditionally lacked bats that could be used for pilot work. Mine corridors and chambers varied in size, with ceiling heights ranging from approximately 4 m to 7 m.

**METHODS**

We received permission from USFWS to enter an Indiana bat hibernaculum and to disturb the bats hibernating there, based on the advances to conservation of Indiana bats that the exercise afforded. During the exercise, all personnel wore caving helmets and used either standard mining or camping headlamps. Personnel included surveyors of most of the largest Indiana bat hibernacula.

Before conducting the main exercise, 5 teams, each consisting of 2 bat researchers accustomed to working together, gathered in a mine passage that did not have Indiana bats in it to work out survey logistics so that the exercise could be carried out efficiently to minimize disturbance to the bats. Pilot work allowed surveyors to become familiar with the local mineralogy and to test photographic and other equipment. Discussion during the pilot exercise focused on how teams would move through the cave and how clusters would be identified for purposes of the exercise. Visual-estimation teams specifically did not discuss details of their survey methods during the main exercise so that cross-team discussion would not influence results.

The day following pilot work, 27 January 2006, the 5 teams and additional support personnel entered the main mine area containing Indiana bats. A single support person selected bat clusters opportunistically as the teams traversed the mine chambers and corridors. Selected clusters provided a wide range of cluster counts (no. of bats in the cluster) and replication within categories of cluster counts. We assigned support personnel ≥ 1 cluster and then guided teams to them, ensuring that teams did not interfere with each other and that all teams estimated numbers of bats in all selected clusters. All groups followed the same path through the mine, and we designated and counted clusters only on the first encounter; to limit disturbance, no clusters were passed and then counted on a later encounter.

One photography team was the first to visit each cluster, and the other was the last. Bracketing the visual estimations with photography allowed us to account for potential changes in bat abundance during the time teams were examining each cluster. Work continued until experienced researchers indicated that bat arousal was about to exceed levels usually seen at the conclusion of a standard survey.

**Estimation Techniques**

Each of the 5 teams used the technique or techniques they customarily used in the field (Table 1). The exercise produced 2 sets of photographs and 4 sets of visual estimates. Every visual estimating team chose to use direct counting for small clusters (typically <60 bats) and a form (in one case, 2 forms) of visual estimation for larger clusters. Teams noted which method was used for each cluster. We refer to the photography teams as Photo1 and Photo2 throughout, and the visual-estimation teams as Estim400, Estim300, EstimX, and Stamping.

Three visual-estimation teams, Estim400, Estim300, and EstimX (as one of its estimation methods), measured or estimated the area of larger clusters and determined numbers of bats using the area and a multiplier representing bat density. The Estim400 and Estim300 used a standard number of bats per unit area, 4,305.56 bats/m² and 3,229.17 bats/m², respectively (400 bats/ft² and 300 bats/ft²; researchers worked in English units). Estim300 used the same density multiplier for all Indiana bat estimation; Estim400, with less experience, used the density multiplier they had been advised to use the previous year. EstimX varied the multiplier by cave, using visual estimation of bat density in the first several clusters observed. For the largest clusters, the team often estimated a cluster-specific density using a row by column (R × C) method for a portion of a large cluster. The R × C method used linear counts of bats in perpendicular directions across a measured portion of the large cluster, multiplying to produce an estimated density, which was then applied to the estimated area of the entire cluster. The team often used the R × C technique with regularly shaped clusters of 60–200 bats, using the product of bat counts in perpendicular directions across the entire cluster to estimate the number of bats directly, without estimating area.

Teams measured cluster areas with rulers or measuring tapes held a few centimeters from the bats, when possible. Estim400 and EstimX estimated dimensions of clusters out of reach of folding rulers and tapes without any assisting devices; Estim300 used a laser caliper device to assist in estimating dimensions. This device consisted of a small box equipped with 2 adjustable laser pointers set to accurately project a 15.24-cm (6-inch) distance when held perpendicular to a distant surface. Area-estimating teams often subdivided irregularly shaped clusters into regular shapes to facilitate estimation.

The team designated Stamping counted or estimated a set number of bats (typically 50–100), determined the area occupied, and visually determined how many like-sized areas could be fit into the remainder of the cluster. We refer to

**Table 1.** Teams and methods used during an exercise to compare different estimation techniques for estimating numbers of bats in hibernacula, Magazine Mine, Alexandria County, Illinois, USA, 27 January 2006. Teams are shown in the order in which they worked.

<table>
<thead>
<tr>
<th>Team identification</th>
<th>Description of method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photo1</td>
<td>Digital photography</td>
</tr>
<tr>
<td>Estim300</td>
<td>Estimate or measure cluster area, multiply by 3,229.17 bats/m² (300 bats/ft²)</td>
</tr>
<tr>
<td>EstimX</td>
<td>Estimate or measure cluster area and estimate density of bats, then multiply. For some regular clusters, estimate no. of bats in a given distance in 2 perpendicular directions across cluster, then multiply</td>
</tr>
<tr>
<td>Stamping</td>
<td>Estimate area of a set no. of bats, then estimate no. of such areas in cluster and multiply</td>
</tr>
<tr>
<td>Estim400</td>
<td>Estimate or measure cluster area, multiply by 4,305.56 bats/m² (400 bats/ft²)</td>
</tr>
<tr>
<td>Photo2</td>
<td>Digital photography</td>
</tr>
</tbody>
</table>
this technique as stamping because the observer takes an observed area and mentally stamps it over the cluster, counting the number of stamps that fill the area. This team typically works in hibernacula where bats are rather close to observers and uses binoculars to count bats on surfaces too distant to allow accurate counting by eye. Both team members made independent estimates, and the team conferred to produce a final estimate.

Both photography teams used 8-megapixel (International Organization for Standardization 100) digital photography. They shot images as close to perpendicular to the cluster as possible. To maximize detail, the photographers tried to fill the image with the cluster. They photographed large clusters in sections with enough overlap to ensure complete coverage for later counting. Photo1, which used photography in its usual survey routine, used a Canon Rebel EOS, with a Canon 100-mm to 400-mm lens (Canon USA, Lake Success, NY), depending on the distance and size of the cluster. Photo1 used aperture (f/11) and shutter speed (1/125 sec) throughout the study, and used a single flash (Canon Speedlite 580EX) on the camera, set on automatic. The camera-mounted flash was supplemented by a hand-held flash (Canon 550EX) on slave mode (flashing simultaneously with the camera-mounted flash) when needed. To minimize illumination and disturbance of bats, photographers used only enough light to identify the outline of the cluster when setting the focal length and centering the image. To reduce illumination still further during focusing, Photo1 traveled with Estim300 and photographed when the laser calipers of that team were directed at the cluster, or used ≥1 handheld, class IIIA laser pointers directed at the cluster. The lasers eliminated the need to illuminate the cluster with a headlamp during focusing and facilitated autofocus by the camera, greatly reducing focusing time. Photo1 took 2 images of each cluster and reviewed image quality on the camera screen to ensure sufficient resolution for counting. Photo2 had not used photography in their previous surveys but used equipment similar to Photo1 during this exercise. They conferred at length with Photo1 before the exercise to ensure similar methods and image quality. Both photography teams reviewed images as they were taken to ensure that countable images were available for all clusters.

Photographers reviewed photos on a desktop computer for image clarity and adjusted using Adobe Photoshop software (Adobe Systems, San Jose, CA), when necessary, to make individual bats discernable. Photographing surveyors identified each digitized bat to species using the same visual markers used in the field. Geographic Information System (GIS) support staff then used enhanced photos as backdrops in ArcGIS. They digitized points onto each bat in the image; they usually used noses to distinguish individuals, but sometimes wings or wrists were more useful, particularly on cluster margins. Digitizing over the image provided a permanent record of the count and permitted secondary observers to check for bats missed by the first observer.

Bats tend to be more tightly clustered in the interior of clusters than at the edges, so knowledge of a regular relationship between bat density and distance to cluster edge might suggest new techniques to estimate numbers of bats in clusters. We selected a subset of photographs taken by Photo1, each of which captured an entire cluster and was taken at an angle close to perpendicular (so that bat dispersal in the cluster would be as accurately represented as possible) and so that the laser-caliper lights used by Photo2 were visible in the photograph. The caliper lights provided a known distance that permitted establishing a spatial frame of reference. We used the ArcGIS Spatial Analyst kernel density-estimation process to calculate density surfaces to determine the consistency of density within clusters and to explore the possibility of using cluster size and shape to estimate bat density. Density calculations require a specified radius of analysis, and density surfaces vary from extremely irregular at small radii to extremely smooth at large radii. We explored radii of 2.54 cm, 3.175 cm, 3.81 cm, and 4.445 cm and used 3.175 cm because it provided sufficient detail to see variation across the cluster but had enough smoothing that variations in local densities (at the scale of 1–2 bats) did not obscure overall trends.

Comparing Team Results
We entered estimates of cluster counts from the 4 visual-estimating teams (Stamping, Estim400, Estim300, and EstimX) and digitized counts of cluster photographs (Photo1 and Photo2) into an SPSS database (SPSS, Chicago, IL). Because comparison of photo counts indicated they were closely matched (see Results) and, therefore, likely to represent the number of bats in clusters accurately, we used the average of the 2 photo counts (hereafter, photoaverage) to designate cluster counts. We used only clusters with photo counts >60 bats to study estimation error because numbers of bats in smaller clusters had a higher probability of being counted, rather than estimated, by at least some teams. We provide descriptive information about results from smaller clusters.

Because both visual and photographic estimation errors were more likely to be proportions of cluster totals than absolute numbers, we present descriptive information about nonphotographic estimates by showing them as proportions of the photoaverages. For the same reason, we use log–log transformations to investigate regression correction of estimates (see next section).

Using Photoaverages to Improve Estimates
We considered 3 methods for improving estimates of cluster counts: 1) substituting photoaverages for estimated counts for some clusters; 2) developing a relationship between estimated and photoaverage cluster counts, based on photographic data from some number of clusters, and using that to modify estimates; and 3) developing a relationship between density and cluster perimeter–area ratio and using that to modify estimates. For the first 2 approaches, we used only the subset of clusters estimated to be >60 bats because visual-estimation teams consistently estimated, rather than counting, above this point.

We explored substituting photoaverages for estimates of larger clusters (clusters estimated to be ≥400 bats and,
separately, clusters estimated to be \( \geq 150 \) bats) for all 4 visual-estimation teams. Because teams estimated that few clusters contained \( \geq 400 \) bats, we show results of substituting photoaverages for all such clusters. Teams estimated that from 16 clusters to 25 clusters had \( \geq 150 \) bats. To simulate photographing all or limited numbers of clusters of \( \geq 150 \) bats, we show results of substituting photoaverages for all such clusters and for bootstrapped results of the range of results possible from substituting photoaverages for only 3 and only 6 such clusters.

We based the substitutions on the estimated cluster count because surveyors in the field have only their own estimates on which to base the decision to photograph a cluster. Because estimated cluster counts varied from team to team, the number of clusters substituted and the proportion of photograph-counted bats in those clusters varied during these analyses. According to the photoaverages used to represent true cluster counts, 3 clusters contained \( \geq 400 \) bats and comprised \( 28\% \) of the total bats (30% of bats in clusters with photoaverages \( >60 \)). Eleven clusters contained \( \geq 150 \) bats and constituted \( 58\% \) of total bats (64% of bats in clusters with photoaverages \( >60 \) bats).

For teams that used area estimation, data suggested a consistent bias in estimates of cluster count (see Results) that might be corrected using a regression approach. We used Monte Carlo simulation (\( n = 20,000 \) iterations) to simulate 2 levels of photography to support regression correction. For both levels, we simulated photographing all large clusters, using the photoaverages for all clusters estimated to contain \( \geq 400 \) bats. For the lower level of photography, we added the photoaverages for 3 randomly chosen, smaller clusters and used the combined sample for regression; for the higher level, we added photoaverages for 6 randomly chosen, smaller clusters. We used 2-stage sampling (\( \geq 400 \) and \( <400 \)) to ensure that the regression correction would be supported by photograph-corrected data across a range of cluster counts.

We used the photographed clusters in a 2-stage process to correct estimates. First, we substituted photoaverages for estimates for any clusters photographed in the simulation. Second, we regressed the natural logs of the estimates for photographed clusters against the natural logs of photoaverages and used the regression line to correct all estimates for clusters not photographed in the simulation. This approach adjusted both for systematic errors in area estimation and for systematic errors in density estimation and simulated a process that would be logically feasible in the field. We used log–log regression because errors were most likely to be proportional rather than absolute.

Finally, as a third strategy, we used photographs of clusters to look for predictable variation in bat density within clusters, as described earlier.

**RESULTS**

Personnel stopped estimating bat numbers 120 minutes after entering the mine, when overall disturbance to the bats, in terms of the proportion of bats roused and flying, was about to exceed levels that experienced surveyors typically encounter at the end of standard population surveys. All personnel had exited the mine by 140 minutes after entering (the bat clusters had been located some distance away from the mine entrance). During the exercise, we designated 52 clusters; all estimating and photographing teams visited all clusters. Using photoaverages to designate cluster counts, cluster counts ranged from 2 to 1,166 (Fig. 1). We encountered few large clusters during the exercise; we designated all such clusters for estimation and photography.

**Consistency of Photo Counts**

There was generally close agreement between the 2 sets of photo counts. Two-thirds of the clusters had differences of \( \leq 2 \) bats. The totals from the photoaverages for the 52 clusters, 8,145 and 8,262, differed by 117, \( <1.5\% \) of either total. The largest difference, occurring for the largest cluster, was 44 bats (<4% of the photoaverage); this was the last cluster observed and at least part of the difference was a true difference resulting from bats rousing and leaving the cluster. The absolute difference was typically \( <6\% \) of the photoaverage, with only 2 clusters having \( >10\% \) difference. The average difference as a proportion of the photoaverage was 2.6%. As a proportion of the photoaverage, differences between photograph-based estimates were unrelated to cluster count (\( r_s = 0.065, n = 52, P = 0.649; \) Spearman rank correlation was used to detect any monotonic relationship) and to elapsed time during the experiment (\( r_s = 0.177, n = 52, P = 0.210); \) errors did not become larger as bats roused during the experiment.

**Estimating Bat Densities From Photos**

Examination of density surfaces produced using spatial analysis of the digitized bats in 7 selected, photographed clusters showed that bat densities within clusters did not vary smoothly with distance from the cluster edge. An exemplar cluster (Fig. 2) shows the common multimodal pattern, lacking any clear relationship between density of bats and distance from cluster edge. Perimeter–area ratios of
Log–log regressions of the estimates against photoaverages for the 31 clusters with photoaverages >60 had a good fit (Shapiro–Wilk tests, all \( P > 0.13 \)) and high explanatory power (Table 3). Results indicated that estimations by 2 teams (Estim300 and EstimX) had significantly increasing underestimation with increasing cluster count; regression slopes were less than and significantly different from 1. Estimates of these teams were internally consistent as evidenced by high \( R^2 \) values.

### Using Photoaverages to Improve Count Estimates

Substituting the photoaverages for visual estimates for clusters that teams estimated to be \( \geq 400 \) bats improved the estimate of total bats for all area-estimating teams (Table 4). Substituting clusters estimated to be \( \geq 400 \) bats did not improve the estimate for Stamping, which showed no strong bias in its cluster estimates, but only worsened it by a percentage point of the photoaverage total. For all other visual-estimating teams, substituting photoaverages for visual estimates of all clusters estimated to be \( \geq 150 \) bats improved estimates of total bats.

We also explored the effect of substituting only some photoaverages, to simulate conditions in which not all clusters are photographed. For the visual-estimation teams that had clear high or low biases (all but Stamping), substituting photoaverages for visual estimates for any 3 or any 6 of the clusters estimated to contain \( \geq 150 \) bats improved the estimate of the total 95–100% of the time (Table 4). For Stamping, which had no obvious bias, substituting counts for visual estimates for 3 clusters estimated to contain \( \geq 150 \) bats produced a total at least as close to the photoaverage total as the estimated total in 63% of cases; substituting for 6 such clusters was at least as good in 70% of cases.

The good fit and high power of the log–log regressions confirmed their appropriateness as tools for correcting biased visual estimates. For Stamping, which had no obvious bias in its cluster estimates, linear regression performed poorly, with 40% of even the more data-rich regression-based estimates (based on all clusters estimated to be \( \geq 400 \) bats and 6 smaller clusters) farther from the photoaverage total than the team’s original visual estimate (Table 5). However, the range of errors, expressed as a proportion of the correct total, remained well within the range of errors produced for the other teams.

For area-estimation teams, all of which showed evident high (Estim400) or low (Estim300, EstimX) biases in

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**Table 2.** Estimated proportional error for clusters of bats with photoaverages of \( \geq 60 \) bats by estimation team and technique. \( P \) values show results of \( t \)-tests of the average ratio of the estimated cluster count to the cluster photoaverage, against an \( H_0 \) value of 1. Data were collected in Magazine Mine, Alexandria County, Illinois, USA, on 27 January 2006.

<table>
<thead>
<tr>
<th>Team</th>
<th>Technique</th>
<th>Average ratio of estimated cluster count to photoaverage</th>
<th>SD of cluster count ratio</th>
<th>( P ) for ( H_0: \text{cluster count ratio} = 1 )</th>
<th>Ratio of estimate to photoaveraged total count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stamping</td>
<td>Stamping</td>
<td>1.09</td>
<td>0.25</td>
<td>0.059</td>
<td>1.034</td>
</tr>
<tr>
<td>Estim400</td>
<td>Area</td>
<td>1.46</td>
<td>0.37</td>
<td>&lt;0.001</td>
<td>1.416</td>
</tr>
<tr>
<td>Estim300</td>
<td>Area</td>
<td>0.83</td>
<td>0.17</td>
<td>&lt;0.001</td>
<td>0.764</td>
</tr>
<tr>
<td>EstimX</td>
<td>Mixed</td>
<td>0.86</td>
<td>0.14</td>
<td>&lt;0.001</td>
<td>0.814</td>
</tr>
<tr>
<td>EstimX</td>
<td>Area</td>
<td>0.83</td>
<td>0.12</td>
<td>&lt;0.001</td>
<td>0.014</td>
</tr>
<tr>
<td>EstimX</td>
<td>R × C</td>
<td>0.89</td>
<td>0.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
cluster count estimation, linear regression, which corrected for systematic errors in both area estimation and density estimation, performed well. For total bats, >99% of regression-corrected estimates were closer to the photoaverage total than the teams’ original estimates (Table 5).

**DISCUSSION**

The data collected during the Magazine Mine exercise speak to accuracy and consistency within and among teams of bat surveyors and among their techniques. During photography (and in the experience of the NY team, which only photographs during surveys), the structure of bat clusters did not typically obscure more than the occasional bat from the camera, and photographic results had strong agreement. Photo counts are thus accurate and repeatable. These characteristics make photography the best estimating technique among those used during this exercise. The use of GIS to mark the position of individual bats in photographic images provided a permanent record of bat counts and also allowed experienced observers to check digitized counts made by less-experienced observers. Photography does not provide truth, however, merely more accurate and repeatable estimates.

**Reducing Bias and Improving Accuracy**

When bias is not present, the primary benefit of photography is to reduce between-year variability in surveys. When bias is present, photography strongly increases accuracy as well as reducing between-year variability. Low between-year variability improves trend detection and is critical for good decision-making concerning the status of imperiled species.

Where most large clusters can be photographed (or clusters containing most bats), substitution of photo counts for visual estimates is simple and produces totals that are very rarely less accurate than visual-estimation techniques used in this exercise and then only marginally. Where substitution improves accuracy, it provides higher power to detect trends than estimates do. Substitution of only some of the large clusters also produced good results when visual estimates were biased and can be used when photography of all large clusters is not possible. When complete photography is not possible, regression with substitution has the best promise for trend detection, provided most large and some smaller clusters are photographed every year.

The larger the bias in visual estimation, the greater was the improvement from the various correction techniques. Bat surveyors should be able to estimate their own level of bias readily using a reduced form of this experiment; they can then choose among correction techniques accordingly. Systematic error (bias), whether a fixed proportion of the true total or a consistent power function of the true total, is largely corrected by regression if a good range of cluster counts and a good sample of clusters can be photographed. Thus, partial photography (at least) may be useful for reducing or eliminating systematic error when accuracy is needed in individual counts (e.g., to compare hibernaculum counts to counts given as down-listing criteria). For best trend detection when complete photography is impossible or impractical, as many relatively large clusters as possible should be photographed, but several small clusters should also be photographed, if regression is to be part of the correction.

During this exercise, surveyors using visual-estimation techniques (with the exception of Estim400) had long practice in their individual techniques; our results do not provide a basis for recommending a visual-estimation technique to new researchers. In addition, no single visual-estimation technique used here was superior both in internal consistency and in low bias; Stamping had the lowest bias, whereas the area-estimation techniques had the highest internal consistency.

**Photography Approaches and Limitations**

Recent advances in sensor resolution allow photography of even quite high ceilings (20–25 m) with handheld cameras, especially if assisted by a bright laser pointer. Clusters that must be photographed at short ranges (<30–60 cm) might be approached using a guided-camera track system to control the camera position and to permit a quick series of overlapping photos in tight conditions.

For some hibernacula, photography may not provide complete counts because of the presence, and use by bats, of narrow crevices and cracks into which monitoring equipment cannot currently be introduced because highly irregular surfaces or oblique photographic angles obscure some portion of a cluster or because bats are scattered in many small clusters that are as readily and accurately estimated as photographed. Such problems are generally obvious when they occur, but may be irremediable. In hibernacula where bats are dispersed in many small clusters, photography may provide little time savings in the field and little improvement in accuracy. Surveyors will need to experiment to determine how well photography works in individual hibernacula and will also need to remain abreast
of technological developments that may allow photography in previously problematical areas. Experimentation in photographic techniques can be carried out in hibernacula during summer, when bats are not present. In gated caves, in which human visitation is controlled or denied, ceiling markers and camera guides might be placed permanently to assist with photography (or, in the case of ceiling markers, also with estimation). Photography can be as fast as, or faster than, other techniques in time spent in the hibernacula, but this will not always be the case. In caves in which photography is straightforward, speed may be limited primarily by the speed of the support staff who record image and cluster information and track which clusters have been photographed. Photography requires lower illumination in general and less prolonged illumination of larger clusters than do visual-estimation techniques. In sites at which mixed, multiple species or mixed species clusters are found, no field time need be spent distinguishing among species.

Photography also allows the opportunity to review results and archive information for future analysis. The value of such an archive has recently been highlighted in ongoing research to determine the etiology, ecology, and epidemiology of a new threat, called white-nose syndrome (WNS), affecting bats in the northeastern United States from western Massachusetts and eastern West Virginia, USA, to central Pennsylvania and eastern West Virginia, USA (Blehert et al. 2008). Because New York has traditionally used photography for its Indiana bat surveys, those images were available for reexamination for visual signs of WNS (i.e., white fungal growth) in years prior to its initial discovery. Although photography may save time in the field, it also be substantially. The application of image-recognition software may significantly reduce costs associated with photographic surveys and offers the opportunity to standardize efforts across most hibernacula. The United States Forest Service recently completed a pilot study demonstrating that image-recognition techniques were feasible and that additional development was warranted (Hamilton et al. 2009). In addition, other new technologies that avoid direct observation of hibernating bats are regularly being tested in hibernacula, which ongoing developments in the use of Table 4: Results of substituting photoaverages of cluster counts of bats for estimates of cluster counts as a ratio of estimated total to photoaveraged total (7,526.5 bats). Ratios and number of clusters substituted are shown for substitution of all clusters estimated to be ≥400 and ≥150 bats and for bootstrapped substitution of 6 and 3 clusters chosen at random from among clusters estimated to be ≥150 bats (n = 20,000 simulation runs for each bootstrap scenario). For bootstrapping results, 5th percentile, 50th percentile (median), and 95th percentile results are shown. We used only clusters with photoaverages of ≥60 bats (n = 31 clusters) in the simulation to ensure numbers of bats were estimated, not counted. Data were collected in Magazine Mine, Alexandria County, Illinois, USA, on 27 January 2006.

<table>
<thead>
<tr>
<th>Team</th>
<th>Ratio of estimated to photoaveraged total</th>
<th>Ratio of totals substituting counts for clusters ≥400 bats</th>
<th>No. clusters substituted</th>
<th>Ratio of totals substituting counts for clusters ≥150 bats</th>
<th>No. clusters substituted</th>
<th>Bootstrap substitution of counts for 6 clusters estimated at ≥150 bats</th>
<th>Bootstrap substitution of counts for 3 clusters estimated at ≥150 bats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stamping</td>
<td>1.03</td>
<td>1.04</td>
<td>5</td>
<td>1.00</td>
<td>23</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Estim400</td>
<td>1.42</td>
<td>1.20</td>
<td>8</td>
<td>1.01</td>
<td>25</td>
<td>1.33</td>
<td>1.37</td>
</tr>
<tr>
<td>Estim300</td>
<td>0.76</td>
<td>0.82</td>
<td>2</td>
<td>0.97</td>
<td>16</td>
<td>0.80</td>
<td>0.84</td>
</tr>
<tr>
<td>EstimX</td>
<td>0.81</td>
<td>0.89</td>
<td>2</td>
<td>0.97</td>
<td>18</td>
<td>0.83</td>
<td>0.86</td>
</tr>
</tbody>
</table>
infrared thermal imaging and beam-breaking systems to count bats exiting from roost caves confirms (Sabol and Hudson 1995, Ammerman 2006, Redell et al. 2006).

MANAGEMENT IMPLICATIONS

When photography of most clusters larger than 100–200 bats is feasible, digital photography provides the most accurate count data for hibernacula and should be a preferred approach. When photography cannot be used throughout a survey, photography of some clusters can permit estimation of error rates and improve the power to detect trends for individual hibernacula. When visual estimations are biased, regression correction involving partial photography is helpful. In these circumstances, photographs should cover the range of cluster counts for which bat numbers are visually estimated, and as many larger clusters as possible should be photographed. When visual-estimation techniques are unbiased, substitution improves estimates when larger proportions of bats are photographed. In the future, as research-team composition or techniques change, particular care will be needed in calculating population trends involving estimates from >1 primary investigator or >1 set of techniques. Doubling up on approaches (e.g., using both estimation and photography) for ≥1 survey of a given cave may improve trend detection for that cave across a time series that bridges teams or techniques.

ACKNOWLEDGMENTS

Permission to undertake this research was granted and travel costs for participants and publication costs were covered by USFWS. Access to the mines was graciously provided by Unimin Corporation; R. Fox provided invaluable on-site support for the exercise. Additional assistance during the exercise was provided by biologists J. A. Duffey, R. K. Dunlap, R. Lindsay, T. L. Osborne, and B. J. Steffen. J. A. Fish and R. G. Thurau provided GIS support. Comments by F. R. Thompson, A. J. Kuenzi, J. McWilliams, R. Britain, and 2 anonymous reviewers were greatly appreciated and improved earlier drafts of the article.

LITERATURE CITED


Associate Editor: Kuenzi.