Wildlife Society Bulletin 1–9; 2021; DOI: 10.1002/wsb.1180

Tools and Technology

Do Remote Camera Arrangements and Image Capture Settings Improve Individual Identification of Golden Eagles?

MARK VUKOVICH,[1,2] *USDA Forest Service, Southern Research Station, P.O Box 700, New Ellenton, SC 29809, USA*
JAMES E. GARABEDIAN, *USDA Forest Service, Southern Research Station, P.O Box 700, New Ellenton, SC 29809, USA*
STANLEY J. ZARNOCH,[3] *USDA Forest Service, Southern Research Station, Clemson, SC 29634, USA*
JOHN C. KILGO, *USDA Forest Service, Southern Research Station, P.O Box 700, New Ellenton, SC 29809, USA*

ABSTRACT Individual identification of animals from camera traps has become an important task in wildlife research, but camera deployment methods often do not facilitate this important undertaking. Identification of individual golden eagles (*Aquila chrysaetos*) is possible using uniquely marked rectrices, but no studies have explored methods to maximize the rate of individual identification from camera images. Our objectives were to assess whether different camera heights (1 m vs. 3 m), image capture settings (one image after a 1-min delay vs. burst of 5 images after a 30 sec delay), and arrangements relative to bait (dorsally vs. ventrally aimed) affected views of rectrices on golden eagles and our ability to identify individuals. We conducted our study from 15 December 2016 to 3 March 2017 on the Savannah River Site, South Carolina. First, we developed a scoring system based on views of rectrices and used a linear mixed-effects model to compare image scores among different camera arrangements and image settings. Next, after identifying individual eagles, we used generalized linear mixed-effects models to compare total individual eagle detections, total days an individual was detected, and probability of obtaining an unknown individual identification among camera arrangements and settings. Overall, we scored a total of 27,499 images, with 8,083 providing views of marked rectrices that allowed identification of 18 individual eagles. Average image scores and proportion of images suitable for individual identification were higher from elevated (3 m) camera arrangements than standard arrangements (1 m) across sites. Regardless of camera height, faster frequency of image capture provided more images that could be used to identify individuals and the most trap days per individual. Researchers and managers should consider deploying elevated cameras traps with faster frequency of image capture to improve data quality and potential for analysis of golden eagle populations and trends across the species' range. Published 2021. This article is a U.S. Government work and is in the public domain in the USA.

KEY WORDS *Aquila chrysaetos*, detection, golden eagles, image processing, rectrices, remote camera.

Recent advances in analytical methods for camera trap data have dramatically improved wildlife population estimates (Royle et al. 2014) and have facilitated novel research on wildlife otherwise too difficult and elusive to study using traditional survey methods (e.g., radiotelemetry, snow-tracking, harvest data; Lofroth and Krebs 2007, Royle et al. 2011). Wildlife research using individuals identified from remote camera traps has focused on medium to large terrestrial mammals like fox squirrels (*Sciurus niger*; Tye et al. 2015), striped skunks (*Mephitis mephitis*; Theimer et al. 2017), tiger (*Panthera tigris*; Karanth et al. 2006), snow leopard (*Panthera uncia*; Jackson et al. 2006), and white-tailed deer (*Odocoileus virginianus*; Weckel et al. 2011). Animals are identified to the individual level based on visible, unique traits and are recaptured again on camera, but in some cases, images of uniquely marked animals may not be of sufficient quality for individual identification (O'Connell et al. 2011, Chandler and Royle 2013). Tailoring camera deployment methods to maximize detection rates and image quality could potentially improve identification of individuals and application of capture-recapture analyses (Alexander and Gese 2018).

Although researchers have recommended approaches for camera deployments in species-specific studies (Magoun

Received: 24 January 2020; Accepted: 20 October 2020
Published:

[1]*E-mail: mark.vukovich@usda.gov*
[2]*Current affiliation: USDA Forest Service, Shawnee National Forest, 602 N 1st St., Vienna, IL, 62995, USA*
[3]*Retired*

et al. 2011, Jachowski et al. 2015), few studies have examined how different camera heights and frequency of image capture settings may affect detection or individual identification of animals. Deploying elevated cameras yielded greater detection probabilities for long-nosed potoroos (*Potorous tridactylus*; Smith and Coulson 2012) and brown bandicoots (*Isoodon obesulus*; Taylor et al. 2014). Likewise, when images were taken from an elevated camera, Theimer et al. (2017) found that volunteer observers scored higher on correct matches and lower on false matches of individually identified striped skunks.

Individual identification of birds from remote camera images is rare because birds present challenges uniquely different than most mammals. Besides being more vagile and smaller-bodied, birds can have multiple molts in a given year, which greatly complicates individual identification based on unique markings. However, larger birds like great gray owl (*Strix nebulosa*), snowy owl (*Bubo scandiacus*), and golden eagles (*Aquila chrysaetos*) may be individually identified using species-specific plumage characteristics like wing patterns (Solheim 2016) or the unique markings on the tail (Watson 2010).

There is growing interest in improving estimation of population status and trends of the golden eagle (Dennhardt et al. 2015, 2017), a protected but declining species (Katzner et al. 2012). Various classes of capture-recapture models could inform conservation efforts, and would benefit from the ability to identify individual golden eagles, a task that could be accomplished using camera traps. Individual identification of golden eagles based on unique plumage markings was first reported from direct observation (Tjernberg 1977, Ellis 1979) and recently using camera traps (Vukovich et al. 2015, Watson et al. 2019). Golden eagles are good candidates for individual identification because they can be baited with carcasses to camera traps during winter months (Katzner et al. 2012, Gjershaug et al. 2019), thus providing the opportunity to maximize detection probability (Jachowski et al. 2015). Further, golden eagles are large birds with unique patterning on their rectrices and a well-documented molt sequence (Bloom and Clark 2001, Ellis 2004, Ellis and Kéry 2004). However, using typical camera trap arrangement (e.g., single cameras positioned approximately 1-m high), many images of golden eagles do not provide sufficient detail for individual identification due to poor angle of view relative to the tail (Vukovich et al. 2015). Additionally, because golden eagles often approach bait from the carcass's dorsal side (Vukovich et al. 2015), strategic placement of camera traps relative to bait carcasses may improve views of rectrices and thus improve likelihood of individual identification.

Our objectives were to assess whether different camera heights (1 m vs. 3 m), frequency of image capture (single image after a 1-min delay vs. burst of 5 images after a 30-sec delay), and position relative to bait (dorsally vs. ventrally positioned) affected views of rectrices on golden eagles and our ability to identify individuals. Our goal was to identify deployment method(s) that: 1) maximize the number of images suitable for individual identification; 2) maximize the number of individuals detected on a given day; and 3) maximize the number of days in which an individual is detected. Deployment methods that maximize images suitable for individual identification, and by extension the number of days individuals are detected, have direct implications for capture histories needed for spatial capture-recapture analyses (Royle et al. 2014). For species like the golden eagle that undergo molts during winter months, maximizing the number of days in which an individual is detected can help track individuals and may increase the likelihood of tracking individuals during periods when unique markings may change (Zimova et al. 2020). Additionally, maximizing the number of individual detections on a given day can improve inferences about behaviors from analyses of spatial and temporal overlap using camera trap images (Caravaggi et al. 2020). We predicted that deploying cameras at a height of 3 m (hereafter, elevated cameras) taking bursts of 5 images after a 30-sec delay would outperform cameras at a height of 1 m taking single images after a 1-min delay (hereafter, standard cameras) and provide higher-quality images that maximize individual detections and number of trap days in which an individual was detected.

STUDY AREA

We conducted our study from 15 December 2016 to 3 March 2017 on the United States Department of Energy's Savannah River Site (SRS), a 78,000-ha National Environmental Research Park in Aiken and Barnwell counties of South Carolina. Loblolly (*Pinus taeda*) and longleaf pine (*P. palustris*) forests dominated upland sites and were managed on 50–120-yr rotations. In the southern portion of the SRS bottomland hardwood and bald cypress (*Taxodium distichum*)-tupelo (*Nyssa aquatic*) forests dominated along the Savannah River floodplain. Prescribed fire management of pine forests was typically conducted at 3- to 5-year intervals.

We selected three bait sites (C27, Beaufort, and TN Rd) for golden eagles that had been used by eagles in at least one previous winter since 2015. Sites were relatively open and flat areas surrounded by 30–100-year old upland pine forests. Site C27 was a 3-year old longleaf plantation with a logging deck that was prepared and maintained by USDA Forest Service personnel. Beaufort was a field maintained for SRS fire operations, and TN Rd was a power line right-of-way maintained in grasses and forbs. Sites were 7.6–21.8 km apart.

METHODS

Carcass Use

Camera trap sites were baited with white-tailed deer (*Odocoileus virginianus*) and wild pig (*Sus scrofa*) carcasses. We obtained a permit from the South Carolina Department of Natural Resources to collect vehicle-killed white-tailed deer in and around the SRS. Carcasses of wild pigs, an invasive species under active control on SRS, were obtained from control program operators who had trapped and euthanized pigs with a .22 caliber rifle using non-lead ammunition. To limit movement of carcasses from a central stationary position relative to deployed cameras, we staked carcasses to the ground by their legs using rebar. We baited sites with a single carcass at a time and removed and replaced old carcass remains when necessary. We deployed 24 carcasses during the study: 5 wild pig carcasses and one deer carcass at C27, 9 wild pig carcasses and one deer carcass at Beaufort, and 8 wild pig carcasses at TN Rd. We visited camera trap sites weekly to check cameras and carcasses and download image data.

Camera Deployment

We deployed six Reconyx cameras (17 PC850, 1 HC600, Reconyx, Holmen, WI, USA) at each of the three sites. We deployed 2 pairs of cameras at 1-m height—one pair positioned dorsally and one pair ventrally relative to carcasses—and a pair of cameras at 3-m height positioned dorsally relative to the carcasses (Fig. 1). We positioned elevated cameras (3-m height) directly above the 1-m high cameras, tilted at a downward angle (45–48°) to center images on carcasses (Fig. 1). For each pair of cameras, we set one to capture a single image after a 1-minute delay and the other to capture a burst of 5 images after a 30-second delay. We oriented all dorsally positioned cameras facing north and all ventrally positioned cameras facing south across sites. We consider all 1-m cameras as standard deployments, as it is typical for researchers to deploy cameras at this height, with motion sensors aimed horizontally.

We securely strapped cameras to either trees or metal posts at each site. For elevated cameras, we used a mounting platform either screwed into trees or attached to metal posts. Mounting platforms permitted flexibility to pan and tilt the elevated cameras at downward angles to center images on carcasses. We placed 1-m cameras side by side or stacked on top of one another on posts or trees and 3.2 m from the center of carcasses. We placed elevated cameras 4.5 m from carcasses and positioned side by side (Fig. 1). To ensure all animals were treated ethically and humanely, we conducted all work to minimize disturbance and avoid direct contact with the animals under study (Fair et al. 2010).

Image Processing

We used a Microsoft Access® database (CPW Photo Warehouse 4.3, Colorado Parks and Wildlife, Denver, CO, USA) to compile and process camera images (Ivan and Newkirk 2016). First, we determined whether the image contained a golden eagle. We then applied a scoring system to rank image quality (1, 2, or 3) based on the views of the dorsal side of golden eagle rectrices. We considered the width and length of rectrices in view for images scored either a 2 or 3. We gave images a score of 3 (good) when the dorsal view of the rectrices included ≥1 whole rectrix and two half rectrices, with ≥50% of the length of one whole rectrix and two half rectrices discernible (Fig. 2a). We gave images a score of 2 (moderate) when the dorsal view of the rectrices included <1 whole rectrix and two half rectrices and <50% of the length of one whole rectrix and two half rectrices were discernible (Fig. 2b). We gave images a score of 1 (poor) if the dorsal side of the rectrices was not visible or otherwise not discernable. Rectrices may not have been visible because the eagle was positioned such that it blocked a clear image of rectrices, or images were too blurry due to an eagle's movement or light conditions. A single observer assigned scores to all photographs.

After scoring all golden eagle images, we used all images scored 2 and 3 to identify individual golden eagles, because these provided moderate to clear views of the dorsal side of eagles' rectrices. We considered eagles identified to the individual level as marked and eagles not identified to the individual level as unmarked. Although we often were able to identify eagles from the two highest scores, it was not always possible to identify every eagle in an image to the individual level. For each individually identified eagle, we assigned a unique identifier (e.g., G1, G2) in order to track the individual throughout the duration of the study. We carefully reviewed and compared individual eagles based on the gray marbling on the rectrices to minimize identification errors (Figs. S1 and S2, available online in Supporting Information; Vukovich et al. 2015). We estimated the position of rectrices of each golden eagle when possible because golden eagles sometimes change overlap of rectrices, particularly the central rectrices (L2–R2), when perched. Golden eagles also undergo molt during the winter and the gray marbling of the rectrices varies across annual plumages making it difficult to identify the same individuals across the entire winter period; hence, we created a reference library of individuals undergoing molt (Fig. 3; Bloom and Clark 2001). We encountered no eagles that had any external markers (e.g. bands, satellite tags) during our study.

For analysis, we only included images captured on days during which all deployed cameras were operational on a given site in order to minimize bias from differences in the number of operable cameras among sites. For cameras that captured a single image after a 1-minute delay, we used the score for the individual image as the response variable in subsequent analyses. For the cameras that captured bursts of

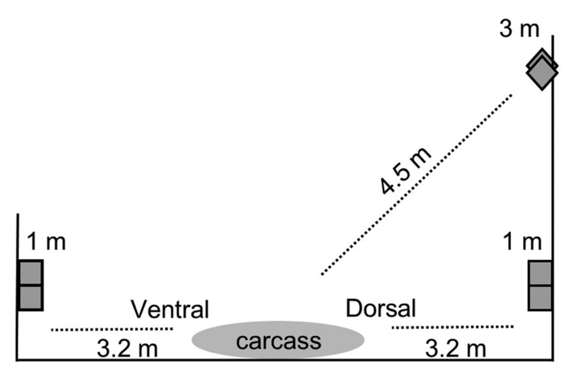

Figure 1. Arrangement of 6 cameras deployed in pairs at a carcass on three sites on the Savannah River Site, South Carolina, USA, 15 December 2016–3 March 2017. In each pair (1-m ventrally to carcass, 1-m dorsally to carcass, and 3-m elevated), one camera was set for 1-min intervals and the other was set for a 30 sec burst of 5 images. Paired 1-m cameras were arranged side by side or in a stacked formation. Paired 3-m elevated cameras were arranged side by side.

Figure 2. Examples of cropped camera images of golden eagles that were given the score of 3 (a) and 2 (b) taken on 1 and 9 January 2017, respectively, on the Savannah River Site, South Carolina, USA. The tail is fully visible and rectrices are spread (a) and the tail is partially spread with less than one whole rectrix and two half rectrices visible (b).

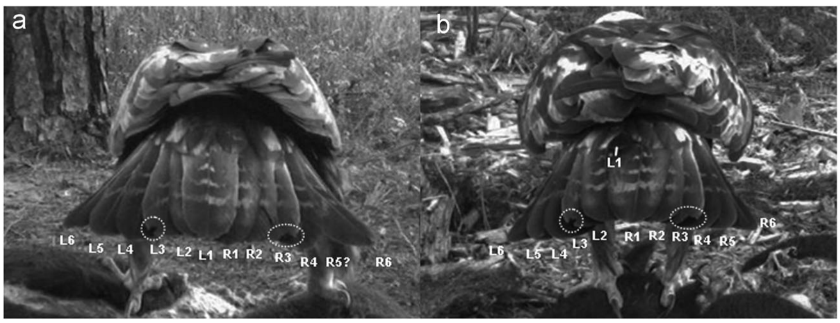

Figure 3. Comparisons of 2 cropped camera images of estimated rectrix positions of an individual Golden Eagle (G1) undergoing molt on the Savannah River Site, South Carolina, USA. Panel (a) shows the rectrices of G1 on 15 December 2016 at TN Rd. Rectrix R5 is not visible or was dropped during molt. Panel (b) shows the rectrices of G1 54 days later on 7 February 2017. Rectrix L1 from the earlier image (a) was dropped during molt and a new replacement L1 (b) is coming in. Rectrices R4, R5, and R6 appear fresh and have recently been replaced (b) when compared to the earlier image (a). Using broken rectrix tips (see dotted circles on L3 and R3) is helpful for tracking individuals across time.

5 images after a 30-second delay, we used the mode of image scores captured during a single burst.

Data Analysis

We used a linear mixed-effects model (LMM) to determine if different camera arrangements and image capture settings influenced image scores and, in turn, our ability to identify individual golden eagles. In the LMM, we modeled the average score of images taken on a given day in response to an interaction between fixed-effects for site and camera arrangement (i.e., camera height and image capture combinations), using trap day as a random intercept term. Although site effects were not a main objective in our study, we included site in our analyses to control for possible confounding effects of site characteristics and historical use.

Next, using only images of individually identified golden eagles, we developed generalized linear-mixed effects models (GLMM) to estimate the effect of camera arrangement and image capture settings on: 1) the number of individual golden eagle detections (i.e., the number of images assigned to any unique individual) on a given day; and 2) number of days an individual golden eagle was identified. As described above, we included site in each GLMM to control for possible confounding site effects. For the first model, we used a Poisson GLMM to model the number of individual golden eagle detections on a given day in response to an interaction between site and camera arrangement, using day and individual golden eagle identification (ID) as random intercepts. For the second model, we used a Poisson GLMM to model the number of days an individual golden eagle was identified (number of trap days) in response to an interaction between site and camera arrangement, using ID as a random intercept.

Finally, for the LMM and GLMMs, we used contrast estimates and 95% confidence intervals to compare effects of camera arrangement on: 1) average score of images (LMM); 2) number of individual golden eagle detections on a given day (first Poisson GLMM); and 3) number of days an individual golden eagle was identified (second Poisson GLMM). We focused interpretation of differences among contrasts on the magnitude of point estimates and the entire range of values within 95% confidence intervals (Nakagawa and Cuthill 2007, Amrhein et al. 2019, Wasserstein et al. 2019). We did not use *P*-values as dichotomous indicators of variable importance or for null hypothesis testing and variable selection; we report them only to provide an additional index of evidence to aid interpretation of effect sizes and confidence intervals (Johnson 2002). We conducted all analyses in the R statistical environment (R Core Team 2019) and used the contributed package glmmTMB (Brooks et al. 2017) to fit mixed-models and the contributed package emmeans for *post-hoc* contrasts (Lenth 2019).

RESULTS

The number of days in which all 6 cameras were operational on a given site was 35 for C27 (3, 12, 18, and 2 days in Dec, Jan, Feb, and March, respectively), 31 for Beaufort (14, 12, 0, and 5 days in Dec, Jan, Feb, and Mar, respectively), and 60 for TN Rd (12, 22, 24, and 2 days in Dec, Jan, Feb, and Mar, respectively). We scored 27,499 images, with most of them receiving a score of 1, and fewer images scoring a 2 or a 3 (Table 1). Overall, cameras set for bursts of 5 images captured after a 30-second delay provided more usable images of golden eagles than a single image captured after a 1-minute delay. The majority of images provided by standard camera deployments were scored 1 (76%–87%), whereas the majority of images provided by elevated cameras were scored 2 (59.3%–60.3%; Table 1; Fig. 4).

The interaction between site and camera arrangement affected the average score of golden eagle images taken on a given day (Tables S1 and S2). Random variation among days and sites accounted for minimal variation among average image scores (for each random term, the standard deviation in average scores was <0.001, or <1%, of the model intercept). Overall, average image scores were highest from 3-m cameras taking one image after one minute, and bursts of 5 images after 30 seconds across sites (Table 2; Fig. 4). Mean differences in images scores were relatively small, likely due to the large number of images from all cameras that received a score of 1, but generally consistent with higher scores of images provided by elevated cameras. Elevated cameras provided images that on average were scored 0.28–0.62 higher compared to standard deployments (Table S3).

We evaluated 8,083 images scored 2 or 3 on days when all 6 cameras were operational at a given site and identified 18 individual golden eagles. Of those images, 3,041 included unmarked or marked but unidentifiable individuals (i.e., those with identifiable characteristics but for which image quality or an individual with similar markings precluded assignment of individual identity). Across all camera arrangements and sites, the average number of detections for an individual golden eagle was 4.5 (SD = 5.4) per trap day, with total detections for an individual for a single camera arrangement and site ranging from 0 to 184 detections (Table S4). Across camera arrangements and sites, the number of trap days an individual golden eagle was detected averaged 8.0 (SD = 6.8) and ranged from 1 to 33 trap days for a single camera arrangement and site (Table S5).

The number of individual golden eagle detections on a given day was affected by the interaction between site and camera arrangement (Tables S1 and S6). Random variation among individuals and trap day (but not site) accounted for considerable variation in the number of individual golden eagle detections on a given day; on average, the standard deviation in number of individual golden eagle detections due to differences among individual golden eagles, differences among trap days, and differences among sites was 0.39, 0.54, and <0.001, respectively (i.e., approximately 39%, 54%, and <1% of the model intercept, respectively). Overall, elevated and standard cameras taking bursts of 5 images after a 30-second delay tended to provide the most individual golden eagle detections on a given day (Table 3). On Beaufort, the full range of 95% confidence intervals indicated cameras taking bursts of 5 images provided 3–8 individual detections on a given day, compared with 1–3 individual detections from cameras taking a single image (Table S7). Patterns on C27 were similar to Beaufort, but were smaller in magnitude and confidence intervals exhibited more overlap (Table S7). On TN Rd there was no consistent pattern indicating cameras taking bursts of 5 images provided more individual detections compared to cameras taking a single image (Tables S7).

Main effects for site and camera arrangement (but not their interaction effect) affected the number of days an individual golden eagle was identified (Table S1 and S8). Random variation among individuals accounted for considerable variation in the number of days a golden eagle was detected (standard deviation in number of days a golden eagle was identified due to differences among individual golden eagles was 0.77 or ~40% of the model intercept). Elevated and standard cameras taking 5 pictures over a 30-second period tended to provide more days in which an individual golden eagle was identified (Table 4). Across all sites and camera arrangements, the full range of 95% confidence intervals were relatively wide (range: 1.8–14.6 days) and exhibited considerable overlap, and mean differences in number of days in which an individual golden eagle was identified ranged from 0 to 4 (Table S9).

DISCUSSION

Our results indicate that camera height is important to consider when designing remote camera trap studies requiring individual identification of golden eagles. Comparisons of mean image scores and confidence intervals did not

Table 1. Total images scored 1 (poor), 2 (moderate), or 3 (good), based on the view of golden eagle rectrices obtained from cameras deployed at 3-m or 1-m heights, image capture settings (one image after a 1-minute delay or bursts of 5 images after a 30-second delay), and orientation relative to carcasses (dorsal or ventral) between 15 December 2016 to 3 March 2017 on the Savannah River Site, South Carolina, USA.

	Image scores			
Camera	1	2	3	Total detections
1-m, 1-min, dorsal	4219 (79.4%)	1036 (19.5%)	53 (1%)	5308
1-m, 1-m, ventral	3124 (87%)	444 (12.4%)	21 (0.5%)	3589
1-m, 30-sec, dorsal	5033 (76%)	1534 (23.3%)	27 (0.4%)	6594
1-m, 30-sec, ventral	4572 (81%)	1085 (19.1%)	10 (0.2%)	5667
3-m, 1-min	843 (38.7%)	1291 (59.3%)	42 (2%)	2176
3-m, 30-sec	1625 (39%)	2511 (60.3%)	29 (0.7%)	4165
Total	19416 (70.6%)	7901 (28.7%)	182 (0.7%)	27499

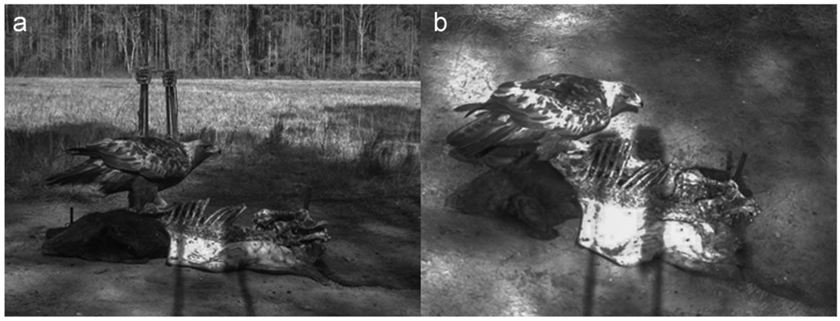

Figure 4. Comparison of cropped images of an individual eagle taken at the same time from a 1-m standard (a) and 3-m elevated deployment (b) at Beaufort on 17 January 2017 on Savannah River Site, South Carolina, USA. In the standard deployment (a) the dorsal-side of the rectrices of the individual are not discernible, but the dorsal side of the same eagle's rectrices and their unique markings are visible from an elevated camera (b).

Table 2. Post-hoc contrast estimates and 95% confidence intervals for average golden eagle image scores ($n = 18{,}381$) across sites and camera arrangements between 15 December 2016 and 3 March 2017 on Savannah River Site, South Carolina, USA. Possible image scores were 1 (poor), 2 (moderate), or 3 (good).

Site	Camera	Mean score	95% CI
Beaufort	1-m, 1-min	1.15	1.12–1.18
Beaufort	1-m, 30-sec	1.16	1.12–1.18
Beaufort	1-m, 1-min, Ventral	1.17	1.13–1.21
Beaufort	1-m, 30-sec, Ventral	1.28	1.25–1.32
Beaufort	3-m, 30-sec	1.57	1.54–1.60
Beaufort	3-m, 1-min	1.66	1.60–1.71
C27	1-m, 1-min, Ventral	1.11	1.08–1.15
C27	1-m, 30-sec, Ventral	1.14	1.11–1.18
C27	1-m, 1-min	1.20	1.16–1.25
C27	1-m, 30-sec	1.23	1.19–1.26
C27	3-m, 30-sec	1.51	1.47–1.56
C27	3-m, 1-min	1.54	1.50–1.58
TN Rd	1-m, 1-min, Ventral	1.13	1.10–1.15
TN Rd	1-m, 30-sec, Ventral	1.14	1.11–1.16
TN Rd	1-m, 1-min	1.27	1.25–1.29
TN Rd	1-m, 30-sec	1.28	1.26–1.31
TN Rd	3-m, 1-min	1.66	1.63–1.70
TN Rd	3-m, 30-sec	1.75	1.72–1.78

adequately reflect the greater proportion of images suitable for individual ID obtained from elevated cameras compared to standard deployments. Elevated cameras produced more usable images compared to standard deployments, likely due to a combination of the increased range of views from elevated cameras and eagle behavior at the carcass. Elevated cameras provided better dorsal images of rectrices even when eagles frequently moved to maintain leverage or adjust their position while feeding on a carcass, and this is reflected by the greater proportion of images scored 2 or 3 compared to standard deployments. Although standard camera deployments (i.e., 1-m height and single images after a 1-min delay) are common and can provide valuable data, in our study they were inferior when eagles shifted positions and positioned their rectrices horizontally or away from the camera. Elevated cameras had a greater range of view from above and could capture shifting golden eagles regardless of bait position. Elevated cameras could also allow for more consistently identifiable images for other animals, whereas standard deployments may yield only partial identification of animals with unique asymmetrical markings (Augustine et al. 2018).

Table 3. Post-hoc contrast estimates and 95% confidence intervals for number of individual golden eagle detections ($n = 1{,}252$) on a given day across sites and camera arrangements between 15 December 2016 to 3 March 2017 on the Savannah River Site, South Carolina, USA.

Site	Camera	Number of individual detections	95% CI
Beaufort	1-m, 1-min	2.17	1.58–2.97
Beaufort	1-m, 1-min, Ventral	2.44	1.78–3.33
Beaufort	3-m, 1-min	2.59	1.94–3.46
Beaufort	1-m, 30-sec	3.68	2.78–4.86
Beaufort	1-m, 30-sec, Ventral	4.74	3.61–6.22
Beaufort	3-m, 30-sec	6.51	5.02–8.43
C27	1-m, 1-min	1.48	1.05–2.08
C27	1-m, 1-min, Ventral	1.55	1.09–2.20
C27	1-m, 30-sec, Ventral	2.70	2.04–3.56
C27	3-m, 1-min	2.79	2.12–3.68
C27	3-m, 30-sec	3.04	2.33–3.97
C27	1-m, 30-sec	3.08	2.35–4.04
TN Rd	1-m, 1-min, Ventral	1.34	1.01–1.78
TN Rd	1-m, 30-sec, Ventral	2.38	1.84–3.08
TN Rd	1-m, 1-min	2.67	2.06–3.45
TN Rd	3-m, 1-min	2.94	2.28–3.80
TN Rd	3-m, 30-sec	3.16	2.46–4.05
TN Rd	1-m, 30-sec	4.00	3.12–5.13

Although elevated cameras produced better images, they typically had fewer total detections compared to standard-height deployments. Others have reported lower rates of detections from elevated cameras, which may be explained by idiosyncrasies of motion sensor capabilities when pointed horizontally versus towards the ground (Kelly 2008, Meek et al. 2016). Lower detection rates from elevated cameras may be more common for medium- to small-sized animals (e.g., ocelots, *Leopardus pardalis*) that are simply more difficult to detect than larger animals (Kelly 2008). Field deployment errors such as poor camera aim could exacerbate low detection rates. Camera manufacturers could facilitate higher detection rates by adding a visual pointer to indicate the camera's aim (e.g., a laser); this should improve camera orientation relative to bait and maximize the likelihood of motion sensors detecting an animal entering the camera field. Alternatively, a remote motion sensor that is deployed

Table 4. Post-hoc contrast estimates and 95% confidence intervals for number of trap days ($n = 155$) per individual golden eagle across sites and camera arrangements between 15 December 2016 and 3 March 2017 on Savannah River Site, South Carolina, USA.

Site	Camera	Trap days per individual	95% CI
Beaufort	1-m, 1-min, Ventral	5.91	3.57–9.77
Beaufort	1-m, 1-min	6.73	4.13–10.98
Beaufort	3-m, 1-min	8.21	5.12–13.16
Beaufort	3-m, 30-sec	8.54	5.34–13.64
Beaufort	1-m, 30-sec, Ventral	9.19	5.79–14.61
Beaufort	1-m, 30-sec	9.23	5.93–14.37
C27	1-m, 1-min	3.14	1.82–5.39
C27	1-m, 1-min, Ventral	4.54	2.68–7.69
C27	3-m, 1-min	5.98	3.76–9.52
C27	1-m, 30-sec	6.44	4.07–10.19
C27	3-m, 30-sec	7.23	4.6–11.34
C27	1-m, 30-sec, Ventral	7.23	4.58–11.42
TN Rd	1-m, 1-min, Ventral	4.23	2.73–6.57
TN Rd	1-m, 1-min	5.55	3.64–8.47
TN Rd	3-m, 1-min	5.64	3.71–8.58
TN Rd	1-m, 30-sec, Ventral	6.76	4.47–10.22
TN Rd	1-m, 30-sec	7.56	5.03–11.36
TN Rd	3-m, 30-sec	7.67	5.11–11.53

horizontally and communicates with the camera to trigger an image may improve detection for elevated camera deployments.

We recorded more detections of individual eagles and more trap days per individual eagle with cameras set to capture a burst of 5 images after a 30-second delay than those taking a single image after a 1-minute delay, regardless of camera height. Faster frequency of image capture provided a greater number of images, which was more likely to include a clear image of eagle rectrices when eagles were moving and shifting positions around the carcass. Despite the width and overlap of confidence intervals for individual detections and trap days across deployment methods, our results suggest faster frequency of image capture can offer practical advantages in research on individuals identified from remote camera images. Faster frequency of image capture provided as many as 10 additional individual detections (on the Beaufort site) and trap days (on the C27 site), and these data are critical for spatial capture-recapture analyses (Royle et al. 2014). Standard deployments with slower settings produce fewer data to analyze and, thus, shorter processing time, but at the cost of reduced precision of spatial capture-recapture analyses. We recognize that in some cases, shorter processing times might be advantageous, such as monitoring species with critical conservation needs (Kelly 2008, Olson et al. 2012) or evaluating the impact of extreme stochastic events on species' distributions (e.g., hurricanes, high-intensity wildfires; Chia et al. 2016, Abernathy et al. 2019). However, when identifying individual eagles is a goal, our results indicate deploying cameras with faster image capture settings offers a practical advantage by providing more higher-quality images of an eagle's rectrices.

Differences in individual detections on a given day and number of trap days per individual among sites may have been related to site fidelity, eagle behavior, and site characteristics. For example, certain eagles may have been more likely to visit and remain at historic bait sites. Indeed, two of the adult eagles observed in this study were detected only on the Beaufort site, which had been a bait site since the winter of 2014–2015. However, the extent of overlap in confidence intervals for number of trap days per individuals across camera arrangements on the Beaufort site suggests that site fidelity has a far greater influence on the number of trap days per individual than camera deployment methods. Additionally, dominant and aggressive eagles (Halley and Gjershaug 1998) may have displaced other conspecifics from a site (Gjershaug et al. 2019), thus reducing the likelihood of obtaining images sufficient for identifying individuals. Finally, site characteristics, like openness, may have interacted with eagle behaviors. For instance, if aggressive eagles were more likely to visit carcasses at open sites with higher visibility, these birds might have displaced conspecifics, further reducing the likelihood of obtaining images sufficient for identifying the displaced conspecifics.

That we could use fewer than one-third of the total images obtained to identify individual golden eagles demonstrates the difficulty in obtaining good views of eagle rectrices, regardless of the camera deployment methods we used. In some cases, a limited number of identified individuals may restrict options for data analysis when the goal is to estimate population density or abundance (Chandler and Royle 2013). However, advances in techniques for analysis of camera trap data allow estimation of population density and distribution using partially marked or completely unmarked populations (Royle et al. 2014). Methods for analysis of partially marked populations would enable us to incorporate an additional 3,041 images of unmarked or marked but unidentifiable individuals from the total 8,803 images scored 2 or 3 in our dataset (i.e., images that provided moderate to clear views of the dorsal side of eagles' rectrices). Further, there is great potential to improve population estimates obtained from spatial capture-recapture analyses by combining telemetry data with camera-trap data of individual golden eagles (Royle et al. 2014). Golden eagle movements have been well-documented from telemetry studies (e.g., Brown et al. 2017). Additional research is needed to explore the extent to which integrating golden eagle telemetry with camera-trap data improves precision of population estimates obtained from spatial capture-recapture analyses.

Our study contributes to the growing body of camera-trap research by highlighting the advantages of tailoring camera deployment methods to improve the likelihood of individual identification and application of capture-recapture analyses. Based on our results, we recommend deploying elevated cameras with faster image-capture settings in camera studies aimed at identifying and tracking individual golden eagles for population monitoring. Elevated cameras using faster image capture settings can offer practical benefits to research using remote cameras by providing better and more images of eagle rectrices, regardless of bait positions and motion sensor idiosyncrasies. As a result, the likelihood of identifying individuals increases and, thus, can improve applications of spatial capture-recapture analyses and aid in monitoring golden eagle populations. However, further research is needed to explore the extent to which alternative camera deployment methods (e.g., elevated cameras deployed as close to directly above bait as possible) can benefit research using camera traps on other taxa. Lastly, preliminary testing indicated a trained convolutional neural network was able to discriminate between high (3) and low (1) scores for our data set and to accurately determine the location of the tail in a large proportion of test images (M. Vukovich, USDA Forest Service, unpublished data). Such programming technology into remote cameras could allow cameras to save only high-quality images of the tail and reduce processing times (Schneider et al. 2019).

ACKNOWLEDGMENTS

We thank S. Davis, R. Geroso, D. Hammett, M. Larsen and T. Wilson for outstanding work in the field, and P. Johns for supplying road-killed carcasses. We thank T. Mims and C. Ruth for assisting with logistics related to this project, and J. M. O'Keefe for reviewing the manuscript. We also thank L. McDonald (Associate Editor), A. Knipps (Editorial Assistant), and 3 reviewers for their comments, which improved the manuscript. Funding was provided by the United States Department of Energy—Savannah River Operations Office through the USDA Forest Service—Savannah River under Interagency Agreement DE-AI09-00SR22188.

LITERATURE CITED

Abernathy, H. N., D. A. Crawford, E. P. Garrison, R. B. Chandler, M. L. Conner, K. V. Miller, and M. J. Cherry. 2019. Deer movement and resource selection during Hurricane Irma: implications for extreme climatic events and wildlife. Proceedings of the Royal Society B: Biological Sciences 286:20192230.

Alexander, P. D., and E. M. Gese. 2018. Identifying individual cougars (*Puma concolor*) in remote camera images–implications in population estimates. Wildlife Research 45:274–281.

Amrhein, V., S. Greenland, and B. McShane. 2019. Retire statistical significance. Nature 567:305–307.

Augustine, B. C., J. A. Royle, M. J. Kelly, C. B. Satter, R. S. Alonso, E. E. Boydston, and K. R. Crooks. 2018. Spatial capture–recapture with partial identity: an application to camera traps. The Annals of Applied Statistics 12:67–95.

Bloom, P. H., and W. S. Clark. 2001. Molt and sequence of plumages of Golden Eagles and a technique for in-hand ageing. North American Bird Bander 26:97–116.

Brooks, M. E., K. Kristensen, K. J. van Benthem, A. Magnusson, C. W. Berg, A. Nielsen, H. J. Skaug, M. Machler, and B. M. Bolker. 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. The R Journal 9:378–400.

Brown, J. L., B. Bedrosian, D. A. Bell, M. A. Braham, J. Cooper, R. H. Crandall, J. DiDonato, R. Domenech, A. E. Duerr, T. E. Katzner, and M. J. Lanzone. 2017. Patterns of spatial distribution of Golden Eagles across North America: how do they fit into existing landscape-scale mapping systems? Journal of Raptor Research 51:197–216.

Caravaggi, A., A. C. Burton, D. A. Clark, J. T. Fisher, A. Grass, S. Green, C. Hobaiter, T. R. Hofmeester, A. K. Kalan, D. Rabaiotti, and D. Rivet. 2020. A review of factors to consider when using camera traps to study animal behavior to inform wildlife ecology and conservation. Conservation Science and Practice 2020:e239.

Chandler, R. B., and J. A. Royle. 2013. Spatially explicit models for inference about density in unmarked or partially marked populations. The Annals of Applied Statistics 7:936–954.

Chia, E. K., M. Bassett, S. W. J. Leonard, G. J. Holland, E. G. Ritchie, M. F. Clarke, and A. F. Bennett. 2016. Effects of the fire regime on mammal occurrence after wildfire: Site effects vs landscape context in fire-prone forests. Forest Ecology and Management 363:130–139.

Dennhardt, A. J., A. E. Duerr, D. Brandes, and T. E. Katzner. 2015. Integrating citizen-science data with movement models to estimate the size of a migratory Golden Eagle population. Biological Conservation 184:68–78.

Dennhardt, A. J., A. E. Duerr, D. Brandes, and T. E. Katzner. 2017. Applying citizen-science data and mark–recapture models to estimate numbers of migrant Golden Eagles in an Important Bird Area in eastern North America. The Condor: Ornithological Applications 119:817–831.

Ellis, D. H. 1979. Development of behavior in the Golden Eagle. Wildlife Monographs 70:3–94.

Ellis, D. H. 2004. Mottling in the plumage of juvenile Golden Eagles. North American Bird Bander 29:53–58.

Ellis, D. H., and M. Kéry. 2004. Variable retention times for rectrices at different loci in a Golden Eagle. Journal of Raptor Research 38:270–275.

Fair, J., E. Paul, and J. Jones, editors. 2010. Guidelines on the use of wild birds in research. Ornithological Council, Washington, D.C., USA.

Gjershaug, J. O., D. Halley, and B. G. Stokke. 2019. Predefinitive plumage in the Golden Eagle (*Aquila chrysaetos*): A signal of aggression or submission? Journal of Raptor Research 53:431–435.

Halley, D. J., and J. O. Gjershaug. 1998. Inter-and intra-specific dominance relationships and feeding behaviour of Golden Eagles (*Aquila chrysaetos*) and Sea Eagles (*Haliatetus albicilla*) at carcasses. Ibis 140:295–301.

Ivan, J. S., and E. S. Newkirk. 2016. CPW Photo Warehouse: a custom database to facilitate archiving, identifying, summarizing and managing photo data collected from camera traps. Methods in Ecology and Evolution 7:499–504.

Jachowski, D. S., T. E. Katzner, J. L. Rodrigue, and W. M. Ford. 2015. Monitoring landscape-level distribution and migration phenology of raptors using a volunteer camera trap network. Wildlife Society Bulletin 39:553–563.

Jackson, R. M., J. D. Roe, R. Wangchuk, and D. O. Hunter. 2006. Estimating snow leopard population abundance using photography and capture-recapture techniques. Wildlife Society Bulletin 34:772–781.

Johnson, D. H. 2002. The role of hypothesis testing in wildlife science. Journal of Wildlife Management 66:272–276.

Karanth, K. U., J. D. Nichols, N. S. Kumar, and J. E. Hines. 2006. Assessing tiger population dynamics using photographic capture–recapture sampling. Ecology 87:2925–2937.

Katzner, T. E., B. W. Smith, T. A. Miller, D. Brandes, J. Cooper, M. Lanzone, D. Brauning, C. Farmer, S. Harding, D. E. Kramer, et al. 2012. Status, biology, and conservation priorities for North America's Eastern Golden Eagle (*Aquila chrysaetos*) population. The Auk: Ornithological Advances 129:168–176.

Kelly, M. J. 2008. Design, evaluate, refine: camera trap studies for elusive species. Animal Conservation 11:182–184.

Lenth, R. V. 2019. emmeans: estimated marginal means, aka least-squares means. R package version 1.3.3. <https://CRAN.R-project.org/package=emmeans>. Accessed (11 November 2020).

Lofroth, E. C., and J. Krebs. 2007. The abundance and distribution of wolverines in British Columbia, Canada. The Journal of Wildlife Management 71:2159–2169.

Magoun, A. J., C. D. Long, M. K. Schwartz, K. L. Pilgrim, R. E. Lowell, and P. Valkenburg. 2011. Integrating motion-detection cameras and hair snags for wolverine identification. Journal of Wildlife Management 75:731–739.

Meek, P. D., G. A. Ballard, and G. Falzon. 2016. The higher you go the less you will know: placing camera traps high to avoid theft will affect detection. Remote Sensing in Ecology and Conservation 2:204–211.

Nakagawa, S., and I. C. Cuthill. 2007. Effect size, confidence interval and statistical significance: a practical guide for biologists. Biological Reviews 82:591–605.

O'Connell, A. F., J. D. Nichols, and U. K. Karanth. 2011. Camera traps in animal ecology: Methods and analyses. Springer, New York, New York, USA.
Olson, E. R., R. A. Marsh, B. N. Bovard, H. L. Randrianarimanana, M. Ravaloharimanitra, J. H. Ratsimbazafy, and T. King. 2012. Arboreal camera trapping for the Critically Endangered greater bamboo lemur (*Prolemur simus*). Oryx 46:593–597.
R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
Royle, J. A., R. B. Chandler, R. Sollmann, and B. Gardner, editors. 2014. Spatial capture-recapture. Elsevier, Amsterdam, Netherlands.
Royle, J. A., A. J. Magoun, B. Gardner, P. Valkenburg, and R. E. Lowell. 2011. Density estimation in a wolverine population using spatial capture-recapture models. Journal of Wildlife Management 75:604–611.
Schneider, S., G. W. Taylor, S. Linquist, and S. C. Kremer. 2019. Past, present and future approaches using computer vision for animal re-identification from camera trap data. Methods in Ecology and Evolution 10:461–470.
Smith, J. K., and G. Coulson. 2012. A comparison of vertical and horizontal camera trap orientations for detection of potoroos and bandicoots. Australian Mammalogy 34:196–201.
Solheim, R. 2016. Identifying individual Great Gray Owls (*Strix nebulosi*) and Snowy Owls (*Bubo scandiacus*) using wing feather bar patterns. Journal of Raptor Research 50:370–378.
Taylor, B. D., R. L. Goldingay, and J. M. Lindsay. 2014. Horizontal or vertical? Camera trap orientations and recording modes for detecting potoroos, bandicoots and pademelons. Australian Mammalogy 36:60–66.
Theimer, T. C., D. T. Ray, and D. L. Bergman. 2017. Camera angle and photographic identification of individual striped skunks. Wildlife Society Bulletin 41:146–150.
Tjernberg, M. 1977. Individual recognition of Golden Eagles (*Aquila chrysaetos*) in the field, and results of winter censuses in southwest Uppland, central Sweden. Vår Fågelvärld 36:21–32.
Tye, C. A., D. U. Greene, W. M. Guiliano, and R. A. McCleery. 2015. Using camera-trap photographs to identify individual fox squirrels (*Sciurus niger*) in the Southeastern United States. Wildlife Society Bulletin 39:645–650.
Vukovich, M., K. L. Turner, T. E. Grazia, T. Mims, J. C. Beasley, and J. C. Kilgo. 2015. Wintering Golden Eagles on the coastal plain of South Carolina. Journal of Field Ornithology 86:337–344.
Wasserstein, R. L., A. L. Schirm, and N. A. Lazar. 2019. Moving to a world beyond "$p < 0.05$." The American Statistician 73:1–19.
Watson, J. 2010. The Golden Eagle, 2nd ed. T. A. D. Poyser, London, UK.
Watson, J. W., M. S. Vekasy, J. D. Nelson, and M. R. Orr. 2019. Eagle visitation rates to carrion in a winter scavenging guild. Journal of Wildlife Management 83:1735–1743.
Weckel, M., R. F. Rockwell, and F. Secret. 2011. A modification of Jacobson et al.'s (1997) individual branch-antlered male method for censusing white-tailed deer. Wildlife Society Bulletin 35:445–451.
Zimova, M., L. S. Barnard, B. M. Davis, A. V. Kumar, D. J. R. Lafferty, and L. S. Mills. 2020. Using remote cameras to measure seasonal molts. Ecosphere 11:e03084.

Associate Editor: L. McDonald.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site. Supporting information includes comparisons of eagle rectrix positions, model results, pairwise differences (scores, individual detections, days), and individual detections across sites and camera arrangements.