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Quantifying detection probability of American woodcock (*Scolopax minor*) on transects sampled with thermal cameras

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Abstract

Developing effective monitoring techniques for sensitive wildlife populations is essential for improving conservation outcomes. The American woodcock (*Scolopax minor*; hereafter woodcock) is an upland migratory game bird traditionally surveyed by documenting displaying males in spring. Surveys of displaying males are limiting in a variety of important ways such as brief detection window and male-centric observations. Thermal technology may overcome limitations of traditional monitoring techniques by increasing detections of non-singing woodcock, however, the efficacy of thermal imaging for detecting woodcock remains unknown. To quantify woodcock detection probability using thermal imaging, we deployed and searched for heat-emitting woodcock mounts along transects within early-successional habitats in central Pennsylvania during 2020. We deployed 110 woodcock mounts and successfully detected 63 (57.2%). Detection rate declined as a function of increasing vegetation density and distance from transect. Although detection probability of woodcock was imperfect, thermal cameras may provide a solution for researchers aiming to assess presence or density of woodcock when coupled with analytical methods that account for imperfect detection.

KEYWORDS

American woodcock, detection probability, old field, *Scolopax minor*, thermal, timber harvest

Monitoring is an important component of species recovery programs (Yoccoz et al. 2001) and affords biologists opportunities to assess population status and trends (James et al. 1996, Link and Sauer 1997, Siriwardena et al. 2000). Monitoring programs also provide biologists and managers insight into how populations respond following conservation efforts like habitat restoration (Castleberry et al. 2002, Cross 2015, Gross 2016, McNeil et al. 2020*a*, *b*). Development of reliable monitoring approaches is central to the implementation of comprehensive and effective conservation efforts (Martin et al. 2007, Menz et al. 2013). Whereas monitoring efforts for some species are relatively straightforward due to high rates of detection (McNeil et al. 2014), more cryptic species require specialized survey protocols to overcome low rates of detection (Southwell et al. 2008, Seamans and Rau 2017).

One species of conservation interest is the American woodcock (*Scolopax minor*; hereafter woodcock; Kelley et al. 2007). Woodcock are a forest-dependent Scolopacid that is distributed across much of the eastern United States (Sheldon 1967, Andres et al. 2012). Populations of woodcock have been steadily declining since at least the 1960s (McAuley et al. 2005, Seamans and Rau 2017). Declines have largely been attributed to the suppression of ecological disturbances (e.g., advancing forest succession, fire and beaver suppression, changes in timber harvest practices) that have resulted in reduced availability of the early successional communities within which woodcock breed (Little 1974, Dessecker and McAuley 2001, King and Schlossberg 2014, Shifley et al. 2014, Seamans and Rau 2017). Given its popularity as a game species, woodcock population declines have spurred habitat management efforts intended to facilitate population recovery (Sauer and Bortner 1991, Kelley et al. 2007, Seamans and Rau 2017, Masse et al. 2019, Johnson 2020). Over the past decade, thousands of acres of early successional wildlife habitat have been created in the eastern United States to benefit disturbance-dependent species (Litvaitis et al. 2021).

While traditional survey methods are effective at leveraging the conspicuous courtship display of male woodcock (Dwyer et al. 1988, Moore and Krementz 2017, Seamans and Rau 2017, Sullins et al. 2019, Johnson 2020), protocols that only consider singing woodcock may misrepresent habitat quality because they fail to consider the presence of females, which do not perform conspicuous flight displays (Van Horne 1983, Longcore et al. 1996, Seamans and Rau 2017). Additionally, habitat used by nesting female woodcock differs from that of singing males (Sheldon 1967, Capel et al. 2008). Thus, male abundance and distribution do not necessarily reflect female nesting density or presence (Dwyer et al. 1988, Seamans and Rau 2017, but also see Tavernia et al. 2018). Similarly, the cryptic plumage and dense nesting habitat used by woodcock make non-vocalizing individuals challenging to detect (Sheldon 1967, Harrison 1975). Further, traditional methods aimed at quantifying woodcock presence or density (e.g., USFWS woodcock Singing Grounds Survey [SGS]; Seamans and Rau 2017) are limited by the very brief period within which surveys are allowed (Rau et al. 2019). Indeed, the SGS, which has long been the primary method for quantifying woodcock populations (Seamans and Rau 2017, Johnson 2020) only allows for 38 minutes of survey time each night and only over a 3-week period each spring (~13 total hours of sampling per year in a given region). In contrast, many diurnal bird species are surveyed for 4–5 hours/day and over a 4-week period, yielding about 10 times the available survey time (Ralph et al. 1995). Therefore, developing methods that quantify the presence of woodcock without relying on counts of singing males is of interest to conservation biologists (Van Horne 1983, Ralph et al. 1995, Sullins et al. 2019).

Although woodcock courtship displays are conspicuous, most other aspects of the species' life history remain cryptic and difficult to study (McAuley et al. 2020). One promising technology that has become increasingly available for surveying cryptic species is the ground-based thermal camera (Blackwell et al. 2006, Chabot and Bird 2015, Shonfield and Bayne 2017, Kays et al. 2019, Karp 2020). Thermal cameras work by converting infrared radiation released by an object (e.g., a warm-bodied animal) into light visible to the human eye (i.e., via a thermogram; Vollmer and Möllmann 2010, Havens and Sharp 2016). Thermal cameras can negate the visual camouflage of endothermic species by converting heat emitted from individuals to a visual wavelength (Havens and Sharp 2016). By allowing an observer to view emitted body heat, otherwise cryptic species are far more readily detected as observers can search for animal heat signatures instead of surface color, pattern, or texture (Mitchell and Clarke 2019, Karp 2020). Although thermal detection of wildlife is not a new application of the technology, thermal surveys have chiefly been restricted to large animals like ungulates (Havens and Sharp 1998, Butler et al. 2006), pinnipeds (Seymour et al. 2017), and cetaceans (Perryman et al. 1999). Recent studies have shown the use of hand-held thermography more efficiently surveys wildlife compared to classic visual methods (Jumail et al. 2021). Though the use of ground-based thermal imagery as a means of monitoring wildlife has been implemented in the past, studies continue to emerge as thermal technology becomes more widely available (Perryman et al. 1999, Ditchkoff et al. 2005, Gauthreaux and Livingston 2006, Keller et al. 2019, Jumail et al. 2021).

Over the past decade, researchers have begun employing thermal technology to survey for non-vocalizing woodcock (e.g., females; Long and Locher 2011) and locate nests (Keller et al. 2019). Although thermal technology clearly holds potential for studying species like the woodcock, the efficacy for detecting woodcock has not been rigorously quantified (Karp 2020, Jumail et al. 2021). Understanding the factors associated with detection probability for species like woodcock is critically important because features (e.g., vegetation density) may be the same variables associated with species presence (MacKenzie et al. 2006, Long and Locher 2011, Keller et al. 2019). When researchers fail to account for detection probability, estimates of occupancy or density are almost invariably biased low (MacKenzie et al. 2006, Guillera-Arroita et al. 2014) and the confounding effects of the observation process and ecological patterns of interest may lead to erroneous conclusions regarding species-habitat relationships (Karp 2020). Here, we designed a study to quantify and model detection probability of non-vocal woodcock on mock surveys using thermal cameras. Specifically, our objectives were to 1) quantify detection probability of woodcock using thermal cameras in early successional communities, and 2) assess the influence of distance-from-observer and vegetation structure on woodcock detection probability along thermal camera transects. We evaluate our results in the context of developing improved sampling methods for cryptic bird species.

STUDY AREA

We studied woodcock detection probability at 3 management units across central Pennsylvania, USA: State Game Lands 176, State Game Lands 276, and Yellow Creek State Park. We selected these management units because all have ample early-successional habitat and are known to support populations of woodcock (L. F. Gray, Indiana University of Pennsylvania, personal communication). As such, each management unit served as a source of woodcock habitat within which to test the efficacy of thermal woodcock surveys under realistic field conditions. State Game Lands 176 (1,914 ha) located in Centre County, was dominated by aspen (*Populus* spp.) and mixed-oak (*Quercus* spp.) forest types. State Game Lands 176 contained several overstory removal timber harvests that varied in age (0–12 years since harvest) and variable levels of understory vegetation density. State Game Lands 276 (1,914 ha), in Indiana County, was dominated by mature mixed-oak forests with old field and shrubland communities interspersed on reclaimed surface coal mines. Yellow Creek State Park (1,206 ha), also located in Indiana County, was comprised of mixed hardwood forests with patches of managed old fields throughout. We focused our sampling efforts within 2 early successional community types commonly used by nesting woodcock: 1) regenerating timber harvests and 2) old fields. We randomly selected 5 old field sites and 7 timber harvests from the 3 management units within which to establish sampling transects. We used the create random points tool in ArcGIS v10.3 (ESRI 2019) to determine start points for our transects. We generated 2–4 random transect locations in each site, with small sites receiving 2 transects and large sites receiving 4 transects. Once the initial sampling points were selected, we drew a 100 m line due north or due south that would translate to a 100 m transect in the field. We also created a second parallel transect 100 m due east or west of the first transect within the early-successional woodcock habitat to maximize survey efficiency while ensuring transect (n = 40) independence.

METHODS

To simulate woodcock occurrences along our transects, we mounted 9 woodcock skins to hollow metal skeletons that allowed for the insertion of heat-emitting hand warmers. Skins were obtained from carcasses provided via hunter harvests, and window or vehicle strikes from several sources following guidelines provided by our federal bird banding permit (No. 23277). Carcasses were frozen and stored until mounting. After thawing the frozen carcasses, we skinned each carcass as if preparing for a study skin and preserved hides using Borax laundry soap (20 Mule Team, Dial Corporation, Edwardsville, IL, USA). To give the woodcock mounts structure resembling a live woodcock, we first constructed an internal torso skeleton from 0.25-in (0.61-cm) hardware wire mesh (Figure 1A). The skeleton was custom fit to match the carcass removed from each woodcock skin and curved to create a hollow pocket for the insertion of a handwarmer. For the neck and legs, we bent and channeled a contiguous piece of 20-gauge steel wire through the torso up (to form the neck) and then back down through the bottom (to form legs; Figure 1A). The legs were then stapled to a wooden base to support each mount during field trials. Additionally, we placed a small piece of aluminum foil molded around the top of the neck wire to mimic the skull and support the beak of each mount (Figure 1B). Upon completing the skeleton, the woodcock skin was mounted in place and sewn on using waxed dental floss (Figure 1C). To simulate a woodcock's body heat, we assessed several brands and sizes of commercially available handwarmers to determine which would function best as a heat source within our woodcock mounts. We found that Hot Hands 10 hour handwarmers (JustBrand Limited, Philadelphia, PA, USA), when divided in half and inserted into the mounts (3 halves/mount), the mounts remained at a fairly consistent temperature (37.7°C) over a 5 hour period without exceeding the temperature of a living bird similar to the size of a woodcock (e.g., Mourning Dove [*Zenaida macroura*]; Bartholomew and Dawson 1954; Figure 1D).

To simulate the process of observing a live woodcock during a transect survey, we placed 0–4 mounts within 20 m of each transect and prompted naïve survey technicians to search for the mounts using a hand-held thermal scope (Pulsar, Helion XP50). Although we did not know the maximum distance at which a nesting or roosting woodcock might be detected, we chose 20 m as a rough approximation for the outer boundary within which most detections would occur based on our preliminary experience using a thermal scope to detect nesting birds within early-successional communities. Transects were delineated by laying out 100 m hip chain string lines from the start point to end point which we also marked with flagging tape. Prior to the survey we randomly selected the total

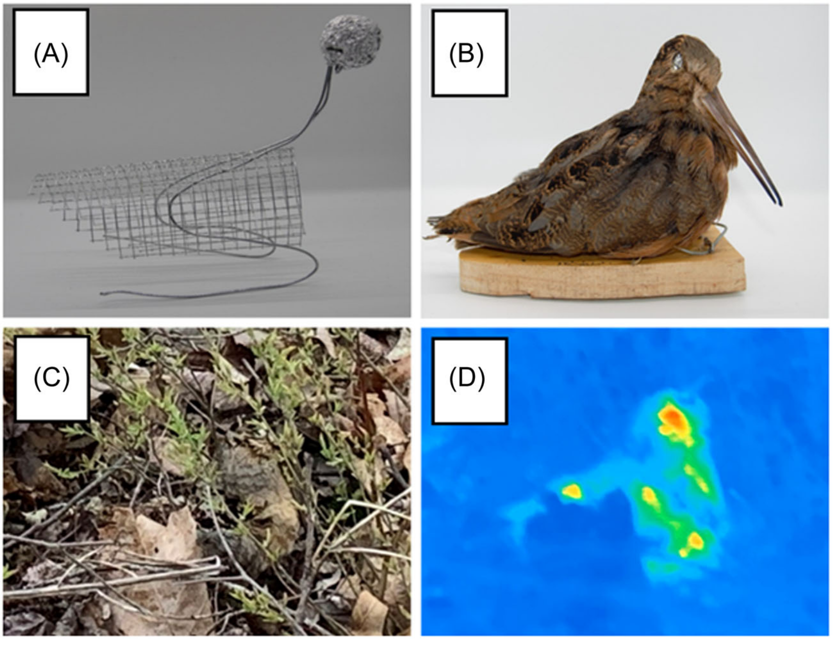

FIGURE 1 The internal metal structure of a mount (A), and the finished woodcock mount ready for deployment (B). Images C and D show a woodcock mount in the field as viewed with the naked eye (C) and through a thermal camera (D). Surveys were conducted from March–April 2020 in central and southwestern Pennsylvania, USA.

number of mounts (0–4) to place along each transect (hereafter, deployment events). We then randomly selected the distance along the transect (0–100 m), side of the transect (East or West), and perpendicular distance from the transect (1–20 m) at which each mount would be placed. Upon the conclusion of mount deployment, independent observers naïve to the placement of mounts (or lack thereof) were equipped with a thermal scope and tasked with slowly walking each transect over a 30 minute period. Because some survey events were characterized by zero woodcock deployment events (i.e., there were no mounts to be found), technicians never knew whether or not a given survey event could yield positive detections. At each transect location, we conducted 1–4 individual survey events (each with different observers). Thermal scopes were set to rainbow color viewing mode with 5 times zoom to maximize the amount of scanned area while displaying high color contrast for objects warmer than the background. Observers paced out and stopped every 5 m and fully scanned 360° undulating up and down to cover as much area as possible during each stop. All thermal surveys were conducted from early-March to mid-April between 0500–0900 and 1700–2300 on days with low solar noise (i.e., days with cloud cover) and ambient survey temperatures between 1.6–10°C. Likewise, surveys were not conducted on days with low ambient temperatures (≤1.6°C) and high winds (≥24 kph) to reduce impacts on woodcock mount visibility.

To quantify structural vegetation along each transect, we measured several structural features within 5, 10 m segments along the length of each 100 m transect (0–10 m, 20–30 m, 40–50 m, 60–70 m, and 80–90 m). The vegetation features we quantified included 1) horizontal vegetation density, 2) woody stem count, and 3) vegetation community type. Each of the 3 features were selected because of their potential impact on detection of a mounted woodcock using a thermal scope. To assess horizontal vegetation density, we used a 2 m tall × 40 cm wide vegetation density board that was divided into 20 squares (each being 20 by 20 cm; Nudds 1977). An observer stood 10 m away from the density board and recorded the number of squares that were >50% obstructed by vegetation. We also estimated woody stem density by counting the number of shrubs or sapling stems within 5, 20-m^2 plots along each transect. Woody stems were included as saplings or shrubs only when their diameter at breast height was <10 cm (McNeil et al. 2017). Vegetation sampling was conducted before leaf-out, concurrent with thermal surveys.

To model the potential impacts of survey and site covariates on woodcock mount detection probability during survey events, we created simple logistic regression models using the glm() function in program R (version 3.6.1; R Core Team 2019). We modeled detection probability of an individual woodcock mount during a survey event as a binary process (1 = detected, 0 = not detected) and allowed detection probability to vary as a function of 4 covariates: 1) perpendicular distance from transect, 2) horizontal vegetation density, 3) woody stem count, and 4) vegetation community type (old field/timber harvest). Each woodcock deployment event was treated as an independent sample. We created all single covariate models as well as all possible combinations of 2 additive covariates. For all competing models containing 2 covariates, we also constructed a model containing an interaction of those covariates and included any interaction models in our final model set. Finally, we also included a null (intercept-only) model for reference. To compare and rank logistic models, we used an information-theoretic approach (Burnham and Anderson 2002). We ranked all models in a single candidate set and compared them using Akaike's Information Criterion adjusted for small sample size (AIC_c). We considered models <2.0 ΔAIC_c to be equivalent and competing. For all competing models, we also assessed covariate β coefficient 85% confidence intervals and interpreted those overlapping zero to have weak effects (Burnham and Anderson 2002, Arnold 2010). For comparison purposes, we also created a density model with our data in program DISTANCE (Thomas et al. 2010), testing several detection functions and estimating density with the best-ranked DISTANCE model; we then compared this estimate to the known density.

RESULTS

From early-March to mid-April 2020, we deployed woodcock mounts along 32 of the 40 transects (15 old field and 17 timber harvest). Eight transects (5 old field and 3 timber harvest) had no woodcock mounts and thus did not contribute data to the detection probability analysis. A total of 110 woodcock mounts were available for detection across 45 survey events (28 old field survey events and 17 timber harvest survey events). The true density of our woodcock mounts was 5.18 mounts/ha (including all 53 transects; 45 with deployment events and 8 without). Woodcock mounts were a mean distance of 10.5 m from transect lines. Of the 110 deployment events, 63 resulted in detection (i.e., detection probability = 57.2% [63/110]). Although we occasionally observed live animals during surveys (e.g., mice [*Peromyscus* spp.], rabbits [*Sylvilagus* spp.], eastern towhees [*Pipilo erythrophthalmus*], and one live woodcock), false detections were readily discerned in all cases from our mounts (by size, shape, and, in the case of the live woodcock, movement) and not officially recorded as mount detections. Horizontal vegetation density along each 100 m transect varied from 6 to 97% (mean = 50%). Woody stem densities in our sites averaged 13,040 stems/ha in old field sites and 22,550 stems/ha in timber harvests. Our detection models indicated that woodcock mount detection probability declined with both increasing perpendicular distance from the transect and horizontal vegetation density (Table 1; Figure 2). There were no models competing with this top model (i.e., others with $\Delta AIC_c \leq 2.0$) and the β coefficient 85% confidence intervals for both the distance-from-transect and horizontal vegetation density covariates in the top model did not overlap zero indicating strong effects. Woodcock mount detection probability declined from 0.84 (95% CI: 0.68–1.00) at 0 m from the transect to 0.18 (95% CI: 0.01–0.35) at 20 m from the transect (Figure 2). Detection probability declined from 0.75 (95% CI: 0.57–0.93) at 0% horizontal vegetation density to 0.27 (95% CI: 0.08–0.47) at 100% horizontal vegetation density (Figure 2). A density model with a negative exponential detection function was best supported by program DISTANCE and estimated the density of woodcock to be 3.50 mounts/ha with 95% confidence intervals (2.11–5.79) overlapping the true density of mounts (5.18 mounts/ha).

TABLE 1 Ranked logistic regression models of mounted American woodcock detection probability from thermal camera surveys in early-successional communities in Pennsylvania, USA, spring 2020. Detection probability was modeled as a binary process (1 = detected, 0 = not detected) which was allowed to vary as a function of perpendicular distance from transect (distance), horizontal vegetation density, habitat type (old field/timber harvest), or woody stem density. For each model, we included the number of model parameters (*k*), Δ Akaike's Information Criterion adjusted for small sample size (ΔAIC_c), model weight (*w*), cumulative model weight (Cum.Wt), and log likelihood (LL).

Model	*K*	ΔAIC_c	*w*	Cum.Wt	LL
Distance + horizontal vegetation cover	3	0.00	0.57	0.57	−43.58
Distance × horizontal vegetation cover	4	2.06	0.20	0.77	−43.50
Distance + woody stem count	3	3.30	0.11	0.88	−45.23
Distance	2	4.31	0.07	0.95	−46.82
Distance + habitat type	3	6.47	0.02	0.97	−46.82
Horizontal vegetation cover	2	7.53	0.01	0.98	−48.43
Horizontal vegetation cover + habitat type	3	8.32	0.01	0.99	−47.74
Horizontal vegetation cover + woody stem count	3	9.62	0.00	1.00	−48.39
Woody stem count	2	12.22	0.00	1.00	−50.78
Null (intercept only)	1	13.91	0.00	1.00	−52.68
Woody stem count + habitat type	3	14.16	0.00	1.00	−50.66
Habitat type	2	16.03	0.00	1.00	−52.68

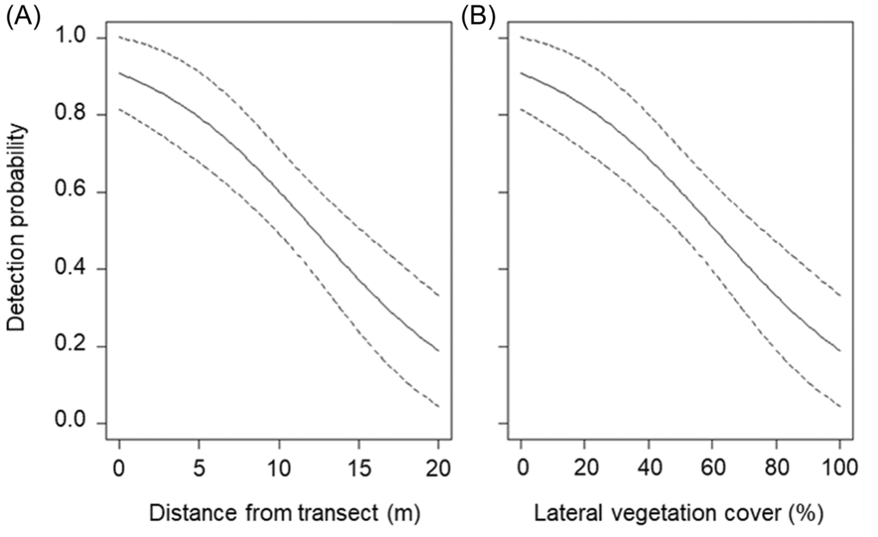

FIGURE 2 Functional relationships between mounted American woodcock detection probability and distance from transect (A), and lateral vegetation cover (B). Solid lines represent density estimates while dashed lines represent 95% confidence intervals.

DISCUSSION

Although we successfully detected mounted woodcocks resembling nesting females (or non-singing males) during many of our survey events (57%), detection was imperfect. The importance of accounting for imperfect detection probability has been recognized in the wildlife literature for decades (Burnham et al. 1980, Buckland et al. 1993, Buckland 2001, MacKenzie et al. 2006). Though thermal cameras allowed us to detect many non-vocalizing woodcock that would have otherwise remained undetected, detection probability was nonrandom. Our results demonstrated that variation in detection probability was, in part, driven by variation in vegetation density and distance from transect. While other studies simply employed thermal technology as a means of finding woodcock (Long and Locher 2011, Keller et al. 2019), our study assessed detection probability for woodcock using thermal cameras. Quantification of detection probability of species surveyed with developing technologies is important because reduced detection rates can have profound implications for the interpretation of monitoring data (Burnham et al. 1980, MacKenzie et al. 2006). Reliable detection of woodcocks, especially nesting females, is essential for assessments of population responses to conservation efforts. As other studies have shown, thermal cameras have potential for monitoring cryptic and elusive wildlife with relatively high detectability (Blackwell et al. 2006, Kays et al. 2019). While woodcock mounts in our study were detected imperfectly, our results provide support for the use of thermal technologies to augment existing survey efforts for woodcock, so long as detection probability is also considered in a modeling framework that accounts for imperfect detection (*e.g.*, distance modeling, occupancy estimation; Williams et al. 2002).

Our work indicated that woodcock detection probability was a function of both primary variables we examined: vegetation density and distance from transect. The relationship between vegetation structure and detection is important because vegetation density is a known driver of woodcock habitat use and nest site selection (McAuley et al. 1996, Dessecker and McAuley 2001), thus confounding the detection and biological processes (Burnham et al. 1980, Buckland et al. 1993). Therefore, employing methods that yield high detection while also accounting for imperfect detection with statistical models is imperative (Williams et al. 2002). The negative relationship between distance and detection probability suggests that woodcock sampling on thermal camera transects would be well-suited for distance-based sampling (Buckland et al. 2005, Thomas et al. 2010, Buckland et al. 2015). In fact, our

DISTANCE density estimate was not distinguishable from the true density of woodcock mounts in the study. The value of distance sampling for studying woodcock is also consistent with recent work in Minnesota demonstrating that woodcock aural detectability, like visual detections of our mounts, decreases with distance and can be modeled with typical detection functions (Bergh and Andersen 2019). Thus, we believe that distance sampling on thermal transects would be a straightforward way to estimate non-singing (e.g., female) woodcock density while accounting for imperfect detection probability because the method requires only one additional piece of information collected in the field: estimated distance from transect (Buckland et al. 2005). One important caveat, however, is that distance sampling assumes detection probability is highest (~1.0) on the transect line (distance = 0 m; Buckland et al. 2005, Buckland et al. 2015). Although we found that some thermal mounts on or near the transect line were not detected, this was uncommon and would likely not occur in nature because a woodcock would undoubtedly flush if encountered at a distance of 0 m, unlike our mounts, thus ensuring their detection. Additionally, although we only deployed mounts out to 20 m, nesting or roosting woodcock can likely be detected farther than this, especially in more open habitats, and truncating observations should be done after unlimited distance sampling is conducted and the true distribution of observations is assessed (Buckland et al. 2005, Thomas et al. 2010, Buckland et al. 2015).

Our study demonstrates the potential for using a transect and thermal camera-based method to detect non-singing woodcock (such as nesting females), either to estimate density or identify nests for monitoring. Nonetheless, there are a few constraints that should be considered when designing monitoring programs that incorporate thermal technology. One such limitation is the decreased effectiveness of thermal cameras as solar radiation exacerbates heat signatures in woody vegetation and abiotic features (i.e., rocks, downed logs, vegetation; Galligan et al. 2003, Stephenson et al. 2019, Jumail et al. 2021). We suggest that thermal based surveys should occur during periods when solar reflectance is absent or limited (Havens and Sharp 1998, Butler et al. 2006). While limiting the time during which sampling could be conducted, thermal imagery would still provide additional hours of woodcock sampling each day, likely increasing sampling time by at least an order of magnitude when compared with traditional vocalization-based methods of survey. Additionally, while we believe our use of warmed woodcock mounts serves as a good proxy for a live, non-singing woodcock, there may be subtle differences in heat signature between a mount and a live bird. During the survey events when we saw live woodcock within the same habitat as warmed mounts, the 2 were indistinguishable (Figure 3) indicating that our mounts were appropriate for our evaluation. Our study provides insight regarding the impacts of imperfect detection on thermal surveys designed to estimate density of ground nesting forest birds like the woodcock. Future work on other, similar species could likely

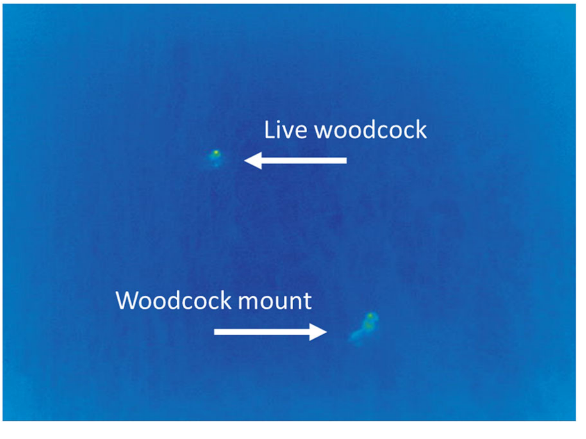

FIGURE 3 A photo taken with a handheld thermal scope (Pulsar-Helion XP50) of a live woodcock (A) near a woodcock mount (B) during a transect survey at Yellow Creek State Park, PA, USA.

implement a similar warm mount dummy transect method to assess detection probability for other wildlife species like eastern whip-poor-wills (*Caprimulgus vociferus*) or ruffed grouse (*Bonasa umbellus*).

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

ETHICS STATEMENT

All woodcock mounts were from specimens held under USGS Bird Banding Permit No. 23277.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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