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Heating decoys to mimic thermal signatures of live animals for drones

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ABSTRACT

Thermal sensors mounted on drones (unoccupied aircraft systems) are popular and effective tools for monitoring cryptic animal species, although few studies have quantified sampling error of animal counts from thermal images. Using decoys is one effective strategy to quantify bias and count accuracy; however, plastic decoys do not mimic thermal signatures of representative species. Our objective was to produce heat signatures in animal decoys to realistically match thermal images of live animals obtained from a drone-based sensor. We tested commercially available methods to heat plastic decoys of three different size classes, including chemical foot warmers, manually heated water, electric socks, pad, or blanket, and mini and small electric space heaters. We used criteria in two categories, 1) external temperature differences from ambient temperatures (ambient difference) and 2) color bins from a palette in thermal images obtained from a drone near the ground and in the air, to determine if heated decoys adequately matched respective live animals in four body regions. Three methods achieved similar thermal signatures to live animals for three to four body regions in external temperatures and predominantly matched the corresponding yellow color bins in thermal drone images from the ground and in the air. Pigeon decoys were best and most consistently heated with three-foot warmers. Goose and deer decoys were best heated by mini and small space heaters, respectively, in their body cavities, with a heated sock in the head of the goose decoy. The materials and equipment for our best heating methods were relatively inexpensive, commercially available items that provide sustained heat and could be adapted to various shapes and sizes for a wide range of avian and mammalian species. Our heating methods could be used in future studies to quantify bias and validate methodologies for drone surveys of animals with thermal sensors.

- We determined optimal heating methods for plastic animal decoys with inexpensive and commercially available equipment to mimic thermal signatures of live animals.
- Methods could be used to quantify bias and improve thermal surveys of animals with drones in future studies.

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Method details

Introduction

Quantifying populations through animal surveys provides basic but key information for wildlife conservation worldwide. Drones, or unoccupied aircraft systems, have rapidly gained popularity in the last decade as critical tools to improve animal surveys across species and geographic areas [1]. Advantages of using drones to survey animal populations compared to ground or other aerial or satellite methods include increased count accuracy, greater efficiency, lower costs, flexible survey schedules, and lower risk of human injury, among others [1,2].

Most studies conducting wildlife surveys with drones use sensors operating in the visible spectrum (Red, Green, Blue; RGB) by which human observers identify and count animals from images or in real time [1]. Surveying animals with Forward Looking Infrared (FLIR) sensors (hereafter thermal) on drones, particularly for nocturnal, cryptic, or species occluded by vegetation, presents new opportunities, especially as image quality and sensor technology improve [1,3–5]. Quantifying bias and driving factors associated with human or automated classification of animals from drone imagery with RGB sensors is improving [6–8], but virtually nonexistent for thermal sensors [1]. Meanwhile, researchers are challenged with creating realistic but controlled experimental frameworks for assessing sampling bias associated with thermal imagery of target species in field settings.

One effective method for quantifying bias and associated drivers is to test humans or train semi or fully automated detection and classification machine-learning algorithms using species-specific decoys in images with known locations, types, and numbers, a typical method for validating RGB drone surveys [6–9]. Alternatively, known numbers of live captive or domestic animals in constrained areas [10] or marked wild animals [11] could be similarly used to assess bias, which have also been conducted for count validation studies with thermal sensors. However, live animals may move during drone flights, which can disrupt accurate counts and make bias quantification difficult [12]. Furthermore, difficulties in finding captive animals of desired species, size classes, numbers, and group sizes, may preclude using live animals to assess bias compared to decoys. Despite its efficacy for visible surveys, using animal decoys compared to live animals to quantify bias in animal classification in thermal surveys suffers from one main problem: decoys do not mimic heat signatures of live animals.

Past studies have investigated handwarmers as thermal proxies for American woodcock (*Scolopax minor*, [13]) or eggs in passerine nests [14]; however, to our knowledge, similar methods applicable to a community of species of various sizes and shapes are unavailable in the published literature. Therefore, we compared inexpensive, commercially available methods to heat plastic animal decoys of three animal size classes to mimic external temperatures and thermal signatures of their respective, live animal species. Developing easy-to-use heating methods for decoys that yield comparable external temperatures and thermal signatures to live animals will provide researchers a foundation for designing future studies to quantify bias in counting and classifying animals from thermal drone imagery among diverse species and environments.

Materials and methods

Study species and overview

We chose rock pigeons (*Columba livia*; hereafter, pigeon), Canada geese (*Branta canadensis*; hereafter, goose), and white-tailed deer (*Odocoileus virginianus*; hereafter, deer), as proxy target species of common North American birds and mammals of different size classes in drone surveys [1]. Pigeon (0.35 kg, [15]), goose (3.8 kg, [16]), and deer (82 kg, [17]), represented our small, medium, and large size classes, respectively.

Using a live animal of each species at captive facilities on and near the campus of Mississippi State University (MSU), MS, U.S.A., we 1) measured external temperatures with a handheld thermometer and 2) captured profile thermal images from an immobile drone 1 m off the ground with the thermal sensor facing forward. We used the external temperature and visual profile from the thermal images from live animals as target values for various body regions to determine how to heat decoys artificially to best approximate external surface temperatures and visually mimic thermal images captured by the immobile drone. After determining the best method of multiple heating methods for decoys to match our evaluation criteria for respective live animals, we conducted a test flight of the drone at varying altitudes, with the sensor in the nadir position (90°), to capture thermal images of our decoys and compare those images against thermal images of their respective live animals.

Heating criteria for decoys to mimic live animals

Animals appear as less distinct shapes of the same approximate size in thermal images compared to visible images, with fewer visible features (Figs. 1 and 2). In thermal images, temperatures of objects in images are relative to ambient temperatures [18]. For each image, temperatures are also binned into relative value categories represented by colors from hottest to coolest [18]. Although

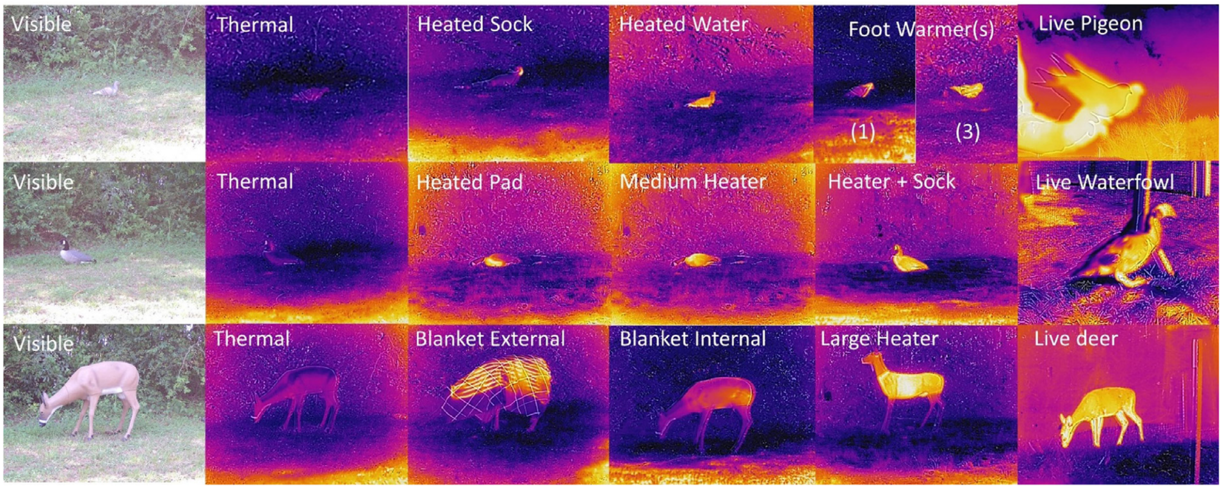

Fig. 1. Thermal images captured by a drone at ground level of plastic decoys heated by various methods compared to non-heated controls (Thermal), visible images (Visible, or Red, Green, Blue), and live animals representing three species: rock pigeons (*Columba livia*, top row), Canada geese (*Branta canadensis*, middle row), and white-tailed deer (*Odocoileus virginianus*, bottom row). Darker colors (black, violet) in thermal images represent cooler temperatures and lighter colors (white, yellow) represent warmer temperatures compared to ambient temperatures. Images for decoys were taken at a standardized distance (6.1 m) but images were cropped and arranged for ease of viewing and are not necessarily to scale.

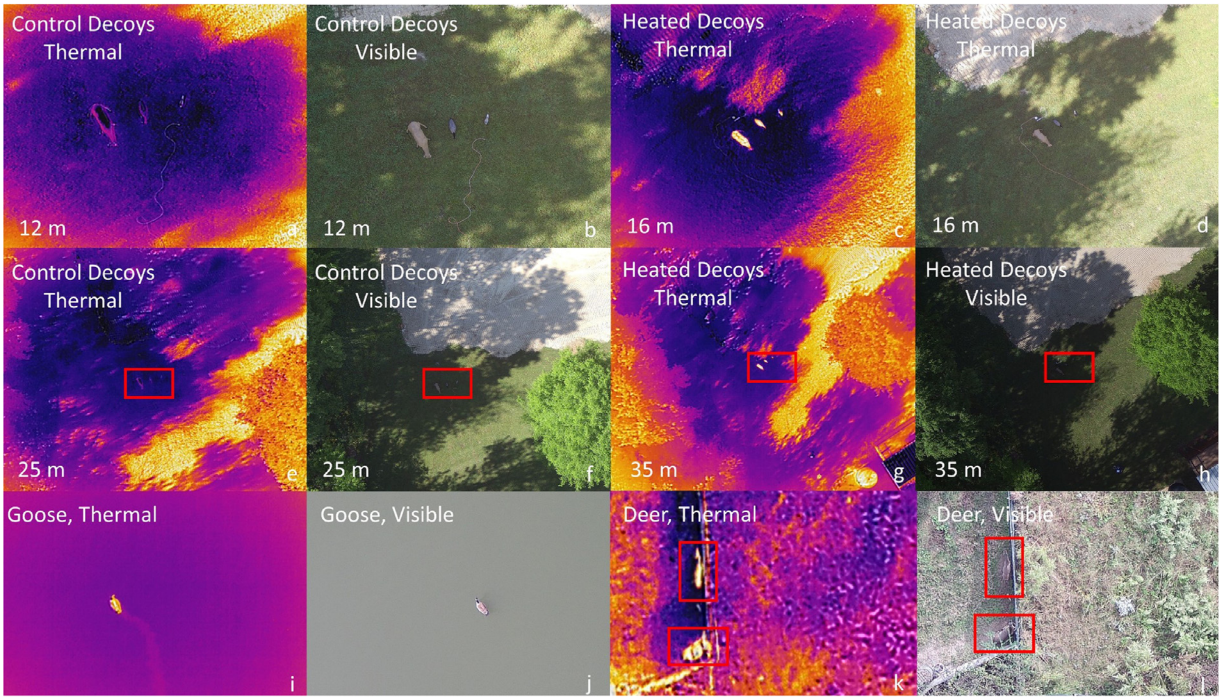

Fig. 2. Thermal and visible images captured by a drone at various altitudes (m) above ground level (AGL) of plastic decoys mimicking three animal species (a – h): rock pigeons (*Columba livia*), Canada geese (*Branta canadensis*, goose), and white-tailed deer (*Odocoileus virginianus*, deer). Thermal controls for decoys were not heated (a, e). Treatment decoys were heated with the method that best matched live animals of respective species (c, g). Live images of a goose on a pond (i, j; 24 m AGL) and two deer in captive pens (k, l; 41 m AGL) to compare to thermal signatures of heated decoys. Red boxes indicate decoy locations at higher AGLs (e – h) or locations of live, cryptic deer (k, l; also zoomed in) that may be more difficult to see. Darker colors (black, violet) in thermal images represent cooler temperatures and lighter colors (white, yellow) represent warmer temperatures compared to ambient temperatures.

Table 1
Temperature (°C) results (mean and standard error) and color bin in thermal images (Bin) by body region for live animals and heated animal decoys using various methods to mimic heat signatures of three animal species: rock pigeons (*Columba livia*, pigeon), Canada geese (*Branta canadensis*, goose), and white-tailed deer (*Odocoileus virginianus*, deer). Some measurements were not taken (indicated by '-') or had only one replicate (live goose, ambient temperatures). Temperature measurements represent values above (no sign given) or below (-) ambient temperatures. Thermal color bins are in order from hottest to coldest as white (W), yellow (Y), orange, (O), red (R), pink (P), violet (V) and black (B).

Species	Method	Head		Body		Tail		Wing or leg	
		°C	Bin	°C	Bin	°C	Bin	°C	Bin
Pigeon	Live animal	16.2 ± 1.0	Y	15.4 ± 0.1	Y	7.6 ± 0.5	O	–	Y
Pigeon	Control	1.0 ± 0.1	V	0.5 ± 0.2	V	0.4 ± 0.3	V	0.8 ± 0.3	V
Pigeon	Heated sock	3.2 ± 0.5	Y,P	0.2 ± 0.1	V	−0.2 ± 0.3	V	0.3 ± 0.2	V
Pigeon	Heated water	7.6 ± 1.5	O	7.8 ± 1.4	Y	4.0 ± 1.4	Y	6.3 ± 1.9	Y
Pigeon	1 foot warmer	15.8 ± 1.3	Y	7.1 ± 0.7	P	1.4 ± 0.2	V	2.6 ± 0.2	P
Pigeon	3 foot warmers	29.2 ± 2.4	Y	35.3 ± 5.8	Y	4.1 ± 0.6	Y	40.0 ± 1.1	Y
Goose	Live animal	9.0	Y	9.9	Y,O	10.2	Y,R	–	Y,V
Goose	Control	0.4 ± 0.2	V	−0.1 ± 0.2	V	0.3 ± 0.1	V	0.2 ± 0.1	V
Goose	Heating pad (interior)	0.9 ± 0.3	V	4.7 ± 0.6	Y,R	0.9 ± 0.2	P	3.9 ± 1.3	O,R
Goose	Mini space heater	2.5 ± 0.5	V	25.1 ± 5.3	Y	7.8 ± 1.0	O	17.3 ± 2.2	Y
Goose	Mini space heater + sock in head	9.7 ± 3.6	Y,O	17.4 ± 3.6	Y	7.2 ± 0.8	O	14.8 ± 0.3	Y
Deer	Live deer	9.6 ± 1.2	Y	10.6 ± 0.1	Y	7.8 ± 0.4	Y	15.7 ± 0.4	Y
Deer	Control	1.6 ± 0.2	V	1.8 ± 0.4	V	0.7 ± 0.1	V	1.1 ± 0.2	V
Deer	Large blanket heater (exterior)	1.7 ± 0.4	Y,V	4.7 ± 0.6	Y,V	3.2 ± 0.9	Y,R	1.8 ± 0.3	P,V
Deer	Large blanket heater (interior)	2.8 ± 0.4	V	3.5 ± 1.2	O,P	3.5 ± 0.2	O,P	1.0 ± 0.3	P,V
Deer	Small space heater	1.6 ± 3.8	O	24.5 ± 3.4	W,Y	19.1 ± 2.5	Y	0.5 ± 2.7	O,V

color palettes vary, one typical color palette represents the warm color bins (from hottest to coolest) as white, yellow, and orange, and the cool color bins as red, pink, violet, and black (Figs. 1 and 2). Thus, we used criteria in two categories, 1) external temperature differences from ambient temperatures (hereafter, ambient difference) and 2) color bins in thermal images, to determine if heated decoys adequately matched respective live animals in four body regions. For each body region compared to live animals, decoy temperatures had to 1) meet or exceed ambient differences in temperature and 2) match respective color bins. We compared decoy heating methods to determine which methods met the above criteria or provided the closest match to live animals. For final validation, we considered a match as adequate for our purpose if it mimicked the color bins in thermal images taken from a drone the air. Because color bins represent relative values in individual thermal images, temperatures similar to and exceeding live animal temperatures for homeothermic animals (birds and mammals) will appear as the hottest colors (white and yellow) as long as ambient temperatures are not near live animal temperatures [18]. Accordingly, because temperatures in thermal images are relative to ambient temperatures [18], we calculated ambient difference (± ambient temperature) by subtracting the ambient temperature from external temperature measurements for all our comparisons. Because our objective was to visually mimic heat signatures of live animals in thermal drone images with heated decoys based on our criteria, we made no formal statistical comparisons between ambient difference temperatures for live animals and treatments of heated decoys.

External temperatures and profile thermal imaging of live animals from the immobile drone

We measured external surface temperatures (°C) for one individual each of a captive pigeon, goose, and deer using a TG54 FLIR hand-held, laser infrared thermometer (FLIR Systems, Inc., Wilsonville, OR, U.S.A.). The pigeon was held by gripping the feet in one hand, but the other two animals were measured in their pens. We measured external temperatures from the dorsum or center of the following body regions: head, back, tail, and wings (pigeon, goose; center point of wing) or legs (deer; halfway up the outside of the left, rear leg). We replicated each measurement three times within a 5-minute period for one individual pigeon and deer and used the mean as our final temperature measurement for each body region. However, we were only able to take one set of external measurements for the Canada goose, which was less cooperative and moved too much to obtain more measurements (Table 1). We recorded ambient temperatures with an Extech EN510 environment meter (FLIR Commercial Systems Inc., Nashua, NH, USA) and calculated final temperatures as the ambient difference.

To capture thermal images of our three live animals from a drone, we took profile thermal images from a Zenmuse XT2 thermal sensor mounted on a stationary DJI Matrice 200 V2 quadcopter (SZ DJI Technology Co., Ltd., Shenzen, China) placed on the ground or on structures up to 1 m above the ground and from 1 – 5 m from respective animals in captive conditions (Fig. 1). Image capture was conducted manually through the DJI Pilot app on a Samsung T500 tablet (Samsung Electronics America, Inc., Ridgefield Park, New Jersey, USA). We used the default color palette for the XT2 (Fusion) in which the warmest colors were white and yellow and coolest colors were violet and black, as the scale for comparisons among decoys and animals in thermal images (Fig. 2). Because we were unable to take a thermal image of the Canada goose, we captured a thermal image of a captive domestic Muscovy duck (*Cairina moschata*) that was approximately the same size and shape as our target species (Fig. 1).

Decoy external measurements and drone thermal imaging

To investigate means of achieving comparable temperatures between three decoy species and associated live animals, we evaluated heating methods based on equivalent external temperatures for ambient difference and color bins in thermal images between decoys

Table 2
Specifications for equipment used to heat plastic decoys to mimic three animal species: rock pigeons (*Columba livia*, pigeon), Canada geese (*Branta canadensis*, goose), and white-tailed deer (*Odocoileus virginianus*, deer).

Equipment	Company	Dimensions (cm)	Notes
Chemical foot warmer (HotHands Insole Foot Warmer)	Kobayashi	7 × 20	pack of two, adhesive, up to 9 h of heat
Battery-powered heated socks	Lil DiHo	9 × 42	rechargeable battery, 3 heat settings
Electric heating pad	Sunbeam	31 × 36	50 watt, corded
Electric heating blanket	Sunbeam	122 × 152	180 watt, corded
Electric mini space heater	YOUCIDI	7.5 × 12.5 × 3.5	200 watt, corded
Electric small ceramic space heater	Amazon Basics	14.5 × 14.5 × 8	500 watt, corded

and associated live animals in a shaded area at MSU. Heating equipment was tailored to decoy size classes and associated live animal external temperatures. We heated pigeon decoys by 1) placing the decoy inside of a battery-powered sock heater, 2) filling the decoy with heated water, 3) adhering one chemical foot warmer to the outside of the decoy from the head to the tail, or 4) adhering two additional chemical foot warmers (three total) to the sides of the decoy body (Table 2). We heated goose decoys by placing equipment inside the body cavity, including 1) a 50-watt 30.5 × 35.6 cm electric heating pad, 2) a 200-watt mini space heater, or 3) the same heater with a battery-powered sock pushed into the decoy's head. We heated deer decoys using 1) a 121.9 × 152.4 cm electric blanket draped on the outside of the decoy to cover the head to tail and most of the sides of the body, 2) the same blanket spread internally to maximize coverage inside the body cavity, or 3) a 500-watt small space heater inside the body cavity. To improve heat dispersion into the head of deer decoys from the body, we cut out the plastic in the neck that sealed the head compartment from the body compartment using a jigsaw. The heads of all pigeon and goose decoys were already openly connected to body compartments. All corded heating equipment was plugged into a nearby, grounded electrical outlet. All electric heating equipment was set to the highest heating settings available.

For heated decoys, we used similar procedures to measure ambient difference and capture profile thermal images as with live animals. We replicated the decoy heating experiments three times, using a different individual decoy for each species each time. We report the mean and standard error among the three replicates for each body region. To visually compare thermal images of heated decoys with those of live animals from the ground, we captured profile thermal images of heated decoys using the same procedures, drone, and thermal sensor as with live animals, except that the drone was placed 0.5 m above ground and 6.1 m from respective decoys (Fig. 1).

Comparing heated decoys to live animals

Compared to ambient temperatures, live pigeon temperatures and thermal color bins for the head and body (+16.2 and +15.4 °C, respectively; yellow) were warmer than the tail (+7.6 °C, orange, Table 1). Heated pigeon decoys using three-foot warmers most closely matched the live animal compared to other methods (Table 2, Fig. 1). For this method, temperatures were warmer for the head (+29.2 °C) and body (+35.3 °C), although cooler for the tail (+4.1 °C) compared to the live pigeon, but matched the yellow color bin for the head, body, and wing (Table 1). The color bin for the tail (yellow) was one bin warmer compared to the live pigeon (orange, Table 1); however, this difference appeared minimal in drone profile images on the ground (Fig. 1). Using one foot warmer or the heated sock resulted in lower temperatures (+15.8 to −0.2 °C); color bins for the head (yellow) were a match, but not for the other three body regions (pink to violet, Table 1). Using heated water resulted in cooler temperatures for decoys (+7.8 to +4.0 °C) but matched color bins (yellow) for all body regions but the head (orange, Table 1). Anecdotally, water also cooled to near ambient temperatures after 30 – 60 min, which created difficulties to adequately fill decoys and capture subsequent aerial images before decoys cooled.

Temperatures for the live waterfowl (goose proxy) compared to ambient were similar across body regions (+9.0 to +10.2 °C, Table 1). Color bins in body regions were predominantly yellow, with some areas of cooler bin colors (orange to violet) where portions of the cage directly shaded the animal (Table 1, Fig. 1). Using a mini space heater with a heated sock in the head was the best match to the live waterfowl compared to other methods (Fig. 1), providing warmer temperatures (+17.4 to +7.2 °C) but similar color bins (yellow to orange, Table 1). Using the mini space heater alone did not heat the head region adequately (lower temperature of +2.5 °C, violet color bin). In contrast, placing a heating pad in the interior of the decoy created lower temperatures (+0.9 to +4.7 °C) and color bins with cooler colors (orange to violet) in the head, wing, and tail regions (Table 1, Fig. 1).

Live deer temperatures compared to ambient were cooler in the head and body (+9.6 and +10.6 °C, respectively) compared to the legs (+15.7 °C), but all regions produced yellow color bins (Table 1). The best match to a live deer was produced with the small space heater in the body cavity compared to other methods (Fig. 1), providing warmer temperatures (+24.5 and +19.1 °C, respectively) and similar color bins (yellow to orange) in the body and tail (Table 1). The average head temperature was lower (+1.6 °C), but the color bin (orange) was one bin cooler in color than for the live deer (yellow, Table 1). Placing the large, heated blanket internally produced lower temperatures across body regions (+3.5 to +1.0 °C), and color bins were cooler colors in the head (violet) and tail (pink to violet, Table 1). Placing the same blanket externally over the deer produced similar temperatures (+4.7 to +1.7 °C) but improved color bins across body regions (Table 1); however, the thermal image was not visually comparable to the live deer because the heating elements in the blanket produced an artificially contrasting pattern of cross-hatched warm and cool color bins (Fig. 1). No heating method matched temperatures (+1.8 to +0.5 °C), color bins for the legs (orange to violet, Table 1), or thermal images well (Fig. 1).

External temperatures for ambient difference in most body regions for all three live animals and the best methods to heat decoys as viewed from the ground and air corresponded mainly with the yellow color bin in thermal images. Ambient difference temperatures in the bins we classified as yellow only for our data ($n = 15$) ranged from +4.1 to +40.0 °C, but all except three values were ≥ +7.8 °C (Table 1). Ambient difference values for violet bins ($n = 19$), the coolest color bin that dominated thermal images, were −0.1 to +2.8 °C (Table 1) and averaged +0.9 °C. Ambient difference values for other color bins in between yellow and violet ($n = 22$), which were often mixed with either yellow or violet, generally ranged in between (+0.5 to +10.2 °C) the values for yellow and violet color bins (Table 1), with a mean of 4.7 °C.

Method validation

After determining decoy heating methods that best matched live animals, we conducted one ascending drone flight with the sensor in the nadir (90°) position and took multiple images at different altitudes (12, 16, 21, 25, 35 m AGL) to evaluate whether thermal decoys visually mimicked the heat signatures (color bins by body region in thermal images) of respective live animals and controls in drone images. As a control, we captured images of the same unheated decoys from the drone. For additional validation, we also compared images of heated decoys to thermal images of live animals taken previously with the same drone, sensor, and camera angle for two of our three species in the air, a goose on a pond (24 m AGL) and two deer in a captive pen (41 m AGL). The validation and other flights were conducted by a Part 107 certified remote pilot (FAA 2016) at MSU.

Thermal images from the validation flight revealed that color bins for the control decoys (not heated) were cooler colors, predominantly violet and black at all altitudes tested (Fig. 2a and e). For heated decoys, color bins in the images for all three species were predominantly yellow in all body regions visible from the same altitudes (12, 16, 21, 25, 35 m AGL, Fig. 2c and g). Thermal images for a live goose (Fig. 2i) and two deer (Fig. 2k) also exhibited predominantly yellow color bins in respective images.

Conclusions

Three methods for heating plastic decoys of animals in three size classes provided equivalent thermal signatures compared to live animals for almost all body regions in both external temperatures (as the ambient difference) and for color bins in thermal drone images from the ground and similar or better matches in drone thermal imagery among multiple altitudes. Although the legs of the heated decoy deer did not match the live animal, from the aerial perspective of the drone with the sensor in nadir position (90°), the legs were covered by the body and not visible for standing deer, which provided a realistic match to a live deer. We also found that heating decoys to a wide range of external temperatures from approximately +8 to up to +40 °C produced the yellow color in thermal images that matched our live animals, coinciding with previous literature reviewing thermal patterns in homeothermic animals [18].

No single heating method was ideal among our decoy types, which differed in shape and size. Therefore, researchers are encouraged to explore various individual applications and combinations of heating equipment for new animal size classes and shapes to determine an ideal method. The materials and equipment required to produce our best methods are relatively inexpensive, commercially available items that provide sustained heat over long periods of time and could be adapted to various shapes and sizes for a wide range of avian and mammalian species. Electric space heaters worked well for our larger body cavities (e.g., goose and deer) but required a consistent electricity source (200 – 500 W) which could cause potential logistical constraints such as coordinating multiple extension cords and perhaps a portable energy source like a generator. For smaller animals or appendages, we found that multiple foot warmers conveniently adhered to decoy surfaces. Battery-powered sock heaters were similarly portable and could be pushed into appendages or completely cover decoys. Appendages such as deer legs in our study that we did not attempt to mimic correctly could be heated with multiple foot warmers if they were not obstructed by the heated body cavity during a drone survey or if investigating ground-based thermal surveys from a horizontal viewpoint. Collectively, our experiments provide flexible and inexpensive approaches for adequately heating decoys for future studies, such as to quantify sampling error in thermal drone surveys, as has been conducted for visible surveys [6–9], for a wide range of species, including cryptic animals.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Landon R. Jones: Conceptualization, Methodology, Investigation, Writing – original draft, Visualization, Validation. **Cerise Mensah:** Methodology, Investigation, Writing – original draft, Validation. **Jared A. Elmore:** Conceptualization, Methodology, Writing – review & editing. **Kristine O. Evans:** Funding acquisition, Conceptualization, Writing – review & editing. **Morgan B. Pfeiffer:** Conceptualization, Writing – review & editing. **Bradley F. Blackwell:** Funding acquisition, Conceptualization, Writing – review & editing. **Raymond B. Iglay:** Funding acquisition, Project administration, Conceptualization, Resources, Writing – review & editing.

Data availability

Data will be made available on request.

Ethics statements

Our methods were reviewed and approved by the USDA National Wildlife Research Center Institutional Animal Care and Use Committee (IACUC) relative to QA 3224. Project information was also shared with the MSU IACUC Chair and approval was deemed not required according to guiding documents and procedures including the USDA Animal Welfare Regulations, the Office of Laboratory Animal Welfare's FAQ, and the MSU Policy and Procedure Statement on Laboratory Animal Welfare.

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