**Title:** A tri-fold approach to quantify the effect of a common olfactory lure on the detection probability of urban mammals while camera trapping

**Short title:** Effect of lures on camera traps

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**Keywords:** camera traps, occupancy model, olfactory lure, detection probability, urban wildlife

**Manuscript type:** TBD on journal

# Abstract

1. Motion-triggered camera traps are subject to imperfect detection and thus camera trapping surveys need to increase species detectability as part of their study design. One possible way to increase detectability is to lures, which may encourage a species to investigate a given area. Yet, the effectiveness of lures is primarily grounded in anecdotal support rather than quantifiable effectiveness.
2. In this study we used a tri-fold approach to quantify the effect of a common olfactory lure on the detectability of mammals throughout Chicago, Illinois, USA. Our study differs from others in that we deployed two camera traps per sampling unit, spaced apart by 100 m, to assess if lure can modify detectability both within and between sites. At each camera location, we changed lure treatments every seven days and placed either a lure or a non-lure control in view of each camera following a full factorial design. To analyze these data, we developed single-season occupancy models with three distinct observational models to quantify if lure increased the number of days a species was detected, decreased the amount of time to first detection, and / or increased the number of images collected.
3. Lure induced a subtle increase in species detectability. Virginia opossum (*Didelphis virginiana*), responded most to the presence of lure: their daily detection probability rose by roughly 8%, they were photographed 40% earlier, and the number of opossum images doubled. Raccoon (*Procyon lotor*) were photographed about 15% more when lure was present but were not detected on more days or in less time. However, the effect of lure was not always positive—eastern cottontail (*Sylvilagus floridanus*) were photographed 42% less when lure was present.
4. With this tri-fold approach we were able to better understand how wildlife respond to lure while camera trapping, which we could not have done with a single metric. Our results show that lure may not be as beneficial as expected, in terms of increasing detectability, but the choice to use lure likely depend on several factors, including the density of the study species, and the dynamics between the species studied.

**Keywords:** Camera trapping, detection probability, lure, mammals, occupancy model, time-to-detection

# Introduction

Motion-triggered camera traps have become a widely used tool for ecological research and are a regularly adopted methodology for large-scale biodiversity monitoring projects (O’Brien et al., 2010; O’Connel et al., 2010; Magle et al., 2019). As an alternative to live trapping, camera traps passively sample numerous locations simultaneously and do not require the physical restraint of an organism­–thereby eliminating the chances of trap-mortality or injury. Further, camera traps are relatively easy to deploy and can answer many questions about wildlife distribution, abundance, or community composition (Bailey et al., 2014; Burton et al., 2015; Fidino, Simonis, and Magle, 2019). However, as with any wildlife survey technique, camera traps are subject to sampling error which, if not accounted for, can lead to biased estimates in occupancy or abundance (Auger-Méthé 2016, MacKenzie et al. 2017).

Above all sources of sampling error, camera traps are subject to imperfect detection– wherein some species who are present in a sampled habitat patch are not detected (Burton et al. 2015). While imperfect detection may be partly addressed during data analysis (MacKenzie et al. 2017), camera trapping surveys must also look for ways to increase species detectability as part of their study design (O’Connel et al., 2010; Hofmeester et al., 2019). The use of lures or bait has been suggested as a way to increase species detectability (Long et al. 2008). The primary motivation for using lures or bait stems from the notion that they will engage a species sense of smell, sight or hearing and therefore increase the chance a target species investigates the area a camera is deployed (as reviewed by Schlexer, 2008). However, the reasoning behind the use of lures or bait is mostly grounded in anecdotal support rather than quantifiable effectiveness (Schlexer, 2008).

Studies that have quantified the effect of lure or bait typically compare detection probability across independent locations where lure is either present or absent from the view of a camera trap (Garrote et al. 2012; Bischof et al. 2014; Rocha et al. 2016; Suárez-Tangil & Rodríguez 2017). However, by using this type of study design it is difficult to separate the effect of lure from other factors that influence detectability such as species’ abundance (McCarthy et al., 2013), which likely varies between locations. Furthermore, most studies determine the effect of lure with a single metric–the number of days a species was detected in the presence of absence of lure (Suárez-Tangil & Rodríguez 2017). Such analyses preclude other ways lure may influence species detectability, such as decreasing time to first detection (Bischof et al. 2014) or increasing the number of images collected (Rocha et al. 2016). To be able to detect a lure effect, it is critical that varying species’ abundances and detectability metrics be considered in the study design and analysis.

In this study we used a tri-fold approach to quantify the effect of a common olfactory lure on the detectability of a suite of mammalian species in natural areas throughout Chicago, Illinois, USA. Our goals in this study were to determine whether lure 1) increases the number of days a species is detected, 2) decreases the amount of time to first detection, and 3) increases the number of photographs of a species. Our study design differs from previous studies because we deployed two camera traps per sampling unit, spaced apart by 100 m, to experimentally assess if lure can modify detectability both within and between sites. At each camera location, we changed lure treatments every seven days by placing either a lure or a non-lure control in view of each camera following a full factorial design. This arrangement allowed us to quantify if lure increases the chances of detecting a species within a site as they may be attracted to a camera that has lure relative to a nearby camera that does not.

# Methods

## Study area and site selection

## This study was conducted in northeastern Illinois within the Chicago metropolitan area (hereafter Chicagoland). The third largest metropolitan area in the United States, Chicagoland contains an estimated 9.5 million residents, 28% of which live within the city of Chicago itself (U.S. Census, 2013a). For this study we randomly selected 20 locations within forest preserves southwest of downtown Chicago in DuPage and Cook County. These locations (hereafter sampling units) were constrained to be a minimum of 1 km apart from one another, and therefore a given forest preserve could host multiple sampling units (Figure 1). Forest preserves were selected instead of other types of urban green space (e.g., city parks) because they have the greatest mammalian species richness and highest occupancy rates (Gallo et al., 2017). Therefore, in our study area, forest preserves likely represent the ideal green space to quantify the effect of lure on mammal detection probability as many species are likely present.



**Figure 1.** A total of 20 sampling units were selected inside forest preserves to the southwest of downtown Chicago, Illinois, USA (a). Each sampling unit consisted of two camera traps separated by 100 m (b). Each camera trap was strapped to a tree and pointed in a downward trajectory (c) towards a lure or non-lure control (d). During each week of the 4-week study a different combination of lure or non-lure control was placed in view of the two camera traps within a sampling unit following a full factorial design (e).

## Experimental design

Each sampling unit consisted of two Bushnell motion-triggered infrared Trophy Cameras (hereafter camera traps). After placing the first camera trap as close as possible to the randomly selected point for that sampling unit, we walked 100 m in a random direction to set the second camera trap. Camera traps were not placed along evident game trails. Camera traps were set to normal sensitivity to take a single photo with a 30 second delay between capture events so long as it was being triggered (for full specifications see supplemental material). Camera traps were placed inside a metal security box, strapped to a tree roughly 130 cm from the ground, and cable locked. Following this, camera traps were angled at a downward trajectory with sticks to center it on a given experimental treatment, which was located roughly 2.5 – 5.8 m from the camera trap on another tree (Fig. 1c).

We had two treatments for this study, a lure treatment and a non-lure control. For the lure treatment, we used a white 2.5 cm plaster disk saturated with a synthetic fatty acid scent (Predator Survey disks, hereafter FAS; USDA Wildlife Services, Pocatello, Idaho). FAS disksare a commonly used olfactory lure suggested to increase the detectability of mesocarnivores, especially coyote (*Canis latrans*; Roughton 1982, Suárez-Tangil & Rodríguez 2017). The non-lure control was a piece of white cardstock cut to an identical size as the FAS disk. Treatments were contained within a 7.5 cm x 7.5 cm black mesh pouch and nailed to a tree approximately 30 cm from the ground (Figure 1c, see supplemental information for examples of both treatments). The non-lure cardstock and mesh control was used to account for the placement of a novel object in view of a camera when using lure (i.e., a visual control).

For this study, camera traps were deployed for 28 consecutive days between August 27, 2018 and September 25, 2018. This 28-day season was divided into four one-week long sessions. For each sampling unit of two cameras, treatments were changed every week following a full factorial design (Figure 1e). Briefly, for camera traps A and B in a sampling unit, both received non-lure controls on week one which were exchanged for lured pouches on week two. On week three, camera trap A received a new lure pouch while camera trap B was given a non-lure control. The opposite occurred for week four: camera trap A received a non-lure control while camera trap B received a lure pouch (Figure 1). Memory cards were replaced every week. Batteries were replaced on all camera traps at the beginning of week three (or as needed otherwise). To ensure accurate species identification in an image, pictures were identified twice by separate individuals (GB and MF). Infra-red images of tree squirrels were marked as a ‘black & white squirrel’ and were censored from subsequent analyses because the individual within a photo could have either been an eastern gray squirrel (*Sciurus carolinensis*) or fox squirrel (*Sciurus niger*). Color images of tree squirrels were identified to the species level. If there was disagreement between identifications or counts of individuals on animage, the photo was assessed a third time by either EL or MF to determine the correct identification. Of the 11,050 total images collected over this study, GB and MF agreed on 87.38% of image classifications. Of those with disagreement, 41.8% occurred when one identifier tagged an image as ‘empty’ while the other observed a species. The date and time for each image was programmatically collected from its exchangeable image file format (exif) metadata.

## Statistical analysis

We fit three separate hierarchical occupancy models to all species with sufficient data. For simplicity, we explain these models for a single species. In the three models, we assume the occupancy status of a species does not change over the 28-day sampling period and that the probability of occupancy does not vary between sites. Thus, the probability of occupancy, *ψ*, at *s* in 1,…,*S* sites is the following Bernoulli process:

where *zs* is a random binary variable that represents the occupancy status of a species. If the species is present *zs* takes the value of one and is otherwise zero. Such a model is no different than the latent state of an intercept-only occupancy model, which we assume is adequate given the proximity of and similarity between natural areas sampled in this study.

### Observation model one: Does lure increase the number of days a species is detected?

Our first model assumes that days within a sampling week are repeat surveys in which a species may be detected given its presence. This is the most traditional formulation of a hierarchical occupancy model (Kery and Royle 2016). For each of the two *c* cameras deployed at a site and *k* in 1,…,4 weeks of sampling we can model the effect of lure as the following Binomial process:

Where *ys,k,c* is the number of days a species was detected at site *s* on week *k* at camera *c*, *js,k*is the number of days sampled at site *s* on week *k*, and *ps,k,c* is the probability of detecting a species given its presence (i.e., *zs* = 1). We incorporate the presence of lure on species detectabilityvia the logit-link function:

Here, is the log odds a species is detected without lure, is the log odds difference in detection given the presence of lure, is an indicator variable which takes the value one when lure is present at a camera, and is a site-level random effect to account for variability that may exist between sampling locations not attributed to lure (e.g., abundance).

### Observation model two: Does lure decrease the amount of time to first detection?

Instead of increasing the number of days a species investigates the location a camera is deployed, lure may decrease the amount of time it takes to detect a species for the first time (Bischof et al. 2014). To quantify this effect, we instead treat data collection as a continuous time process. Let the response variable of this model, , be the continuous number of days until first detection (i.e., the amount of time it takes to collect the first image of a species per camera each week). If a species is present at a site but not detected after seven days when treatments are changed there is uncertainty regarding how long it would take for the species to be photographed. To account for this, we model as a censored exponential random variable. Let *Tmax* be the maximum amount of time a lure treatment is placed in front of a camera trap (i.e., *Tmax* = seven days). Following Kery and Royle (2016), the continuous time-to-detection observation model is

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Here, is an indicator function which takes the value one if a species is present but not detected in a given week at a camera trap. With this specification equals one if a species is present but went undetected or if they were not present (i.e., *zs* = 0). When this occurs, . Otherwise, equals zero and we sample from the Exponential distribution to estimate the inverse scale parameter from the right-censored data. To estimate the effect of lure on this parameter we use the log-link function

We use a similar parameterization to the logit-linear predictor of the first observation model, except the coefficients in this model are on the log scale. Further, these coefficients estimate the expected time between detection events in the presence or absence of a lure, all while controlling for variability between sites not attributed to lure via the site-level random effect .

### Observation model three: Does lure increase the number of photographs of a species?

Finally, lure may increase the number of images taken of a species if it increases the amount of time a species spends in view of a camera or increases repeat visits within a single day. This may be advantageous if a study species can be identified to an individual level by their markings, such as a leopard’s spots, which is easier to do with multiple images (Rocha et al. 2016). Here, let be the number of images collected of a species as site *s*, week *k*, and camera *c*. We can model the number of images collected as the following Poisson process

where and are the same as before while is a rate parameter which estimates the average number of photos expected per day given a species’ presence. Like model two, is used to control for the observational treatment window length, but functions as an offset term within this model. To incorporate the effect of lure we use the log-link, as we did with model two:

### Specification of priors and model fitting

We took a Bayesian approach to parameterize our models. For all models, we used an uninformative Beta(1,1) prior for the probability of occupancy, *ψ*. For the observational process of each model, the choice of priors depended on the link function. For model one, which uses the logit-link, we followed the suggestions of Gelman et al (2008) and gave the intercept, *a0*, a Cauchy(0, 10) prior while the lure effect parameter (*a1*) received a Cauchy(0, 2.5) prior. For models two and three, the log-link intercept and lure effect parameters received uninformative Normal(0, 10000) priors. Finally, random effects from all models were drawn from Normal(0, σ) distributions where σ ~ Gamma(0.001, 0.001).

Models were executed in JAGS version 4.3.0 (Plummer 2003) through program R version 3.5.2 (R Core Team 2018) via the runjags package (Denwood, 2016). Following a 1,000 step adaptation phase models had a burn-in period of 50,000 steps. After the burn-in, parameters were sampled a total of 300,000 times across 6 chains. MCMC chains were thinned by 5. Model convergence was assessed by visually inspecting trace plots and ensuring that Gelman-Rubin diagnostics for each parameter were < 1.10 (Gelman et al. 2014). Significance of the estimated regression coefficients was calculated by assessing if 95% credible intervals overlapped zero.

# Results

Over the course of this study, cameras were functional for 1,110 days out of a possible total of 1,120 (28 days \* 40 cameras). In this period a total of 6,110 images were collected of 12 different species. Eight species had enough data to fit the three models: coyote, eastern chipmunk (*Tamias striatus*), eastern cottontail rabbit (*Sylvilagus floridanus*, hereafter cottontail), eastern gray squirrel, fox squirrel , raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*, hereafter opossum), and white-tailed deer (*Odocoileus virginianus*, hereafter deer). The remaining four species that had insufficient data were the American mink (*Neovison vison*, three photos at one sampling unit), long-tailed weasel (*Mustela frenata*, one photo at one sampling unit), southern flying squirrel (*Glaucomys volans*, seven photos across two sampling units), and striped skunk (*Mephitis mephitis*, 13 photos across eight sampling units). Eastern gray squirrel were photographed the most over the survey, totaling 1,917 pictures across all 20 sampling units. Of the species that could be analyzed, cottontail were detected the least, totaling 72 pictures across nine of the 20 sampled sites.

## Did lure increase the number of days a species was detected?

Without lure, daily detection probability varied greatly between species (Figure 1). Coyote, for example, exhibited a 5.77% (95% CI = 2.85 – 9.21) probability of being detected each day, which did not increase when lure was placed in front of a camera (Figure 2). Raccoon and gray squirrel had the highest daily detection probabilities without lure, which were respectively 46.09% (95% CI = 36.69 – 55.00) and 47.89% (95% CI = 36.45 – 58.49). The presence of lure significantly increased the number of days two species were detected: opossum and chipmunk. Opossum detection probability increased by 8.20% (95% CI = 3.32 – 13.36) when lure was present to a total daily detection probability of 25.08% (95% CI = 18.03 – 32.46). Lure had a lesser effect on chipmunk detection probability, which increased by 4.76% (95% CI = 0.38 – 10.40). The presence of lure increased raccoon and gray squirrel detection by about 5%, but 95% credible intervals of this effect bounded zero (Figure 2). There was some indication that the daily detection probability of cottontail and deer decreased by about 3% given the presence of lure.



**Figure 2.** Lure had a marginal, but varying effect on the number of days species were detected. The left plot illustrates the daily probability of detecting a species when no lure was in front of a camera. The right plot illustrates how a species detection probability on the left changed given the presence of lure. Vertical solid lines are median estimates which are plotted with the posterior distribution that fell within the associated 95% credible interval.

## Did lure decrease the amount of time to first detection?

Without lure, the expected number of days to first detection ranged from 2.21 (95% CI = 1.12 – 3.69) for gray squirrel to 20.75 days (95% CI = 9.63 – 45.37) for cottontail (Figure 3). When lure was placed in view of a camera most species showed a general decreasing trend in the amount of time to first detection (i.e., were photographed in fewer days; Figure 3). However, credible intervals of this estimated effect bounded zero for all species except opossum. On average, the expected time to detect opossum decreased by 35.34% (95% CI = 11.13 – 55.83) to 5.57 days (95% CI = 3.73 – 7.81). There was some indication that it took longer to detect coyote and cottontail given the presence of lure, but this effect was also not significant (Figure 3).



**Figure 3.** Opossum were the only species to be photographed earlier if a lure was placed in front of a camera. The left plot is the expected number of days until the first photograph is taken, given the presence of a species. The right plot is the proportional effect that lure had on the number of days until a photograph is taken, with values less than one indicating a decrease in the amount of time to first detection. Vertical solid lines are median estimates which are plotted with the posterior distribution that fell within its associated 95% credible interval.

## Did lure increase the number of photographs of a species?

Two species had significantly more photos taken when lure was present: opossum and raccoon (Figure 4). For opossum, the number of images captured increased by a factor of 2.01 (95% CI = 1.66 – 2.38), while the number of images captured of raccoon increased by a factor of 1.15 (95% CI = 1.06 – 1.26). All other species save for cottontail had a marginal but non-significant increase in photos given the presence of lure (Figure 4). Cottontail, on the other hand, were less likely to be photographed given the presence of lure as the number of images collected decreased by a factor of 0.42 (95% CI = 0.25 – 0.62).



**Figure 4**. More images were collected of opossum and raccoon while lure was present, while cottontail rabbits were photographed less. The x-axis represents the proportional change in the number of photos taken of a species when lure was present. Values greater than one indicate that more images were taken.

# Discussion

Our tri-fold approach to quantify the effect of lure on urban mammals offers evidence that the presence of lure may induce, in general, a subtle increase in species detectability. Save for cottontail and deer, most mammals trended towards being detected on more days or earlier in time given the presence of lure, though evidence of this estimated effect is limited as 95% credible intervals often included zero. For species in which we observed a significant effect, opossum had the largest response to lure across all three analyses. When lure was in view of a camera, opossum were detected across more days of a survey (Fig. 2), in a shorter amount of time (Fig. 3), and the number of opossum images doubled (Fig. 4). Raccoon, the only other mesocarnivore for which we observed a significant response to the presence of lure, were photographed 15% more often, but did not arrive any earlier to a camera or display increased detection across multiple days. Together, these findings indicate that lure may provide some increase in species detectability, but the effect of lure likely varies by species and may not be as substantial as expected. Given these mixed results, it is important to weigh the costs and benefits of using lure when designing a camera trap study.

Overall, the decision of whether to use lure while camera trapping will depend on the study species, lure type, study goals, and the time of year camera traps are deployed (for a review see Long et al. 2008). In our study, lure may not be necessary to detect these urban species because they are common and abundant throughout Chicagoland (Gallo et al. 2017). As detectability is partially a function of abundance (McCarthy et al. 2013), lure may not be as needed in studies of common species because detection probabilities are already relatively high (Figure 2). Conversely, studies that focus on rare species such as large terrestrial carnivores require much more sampling effort per successful detection (MacKenzie & Royle 2005; Shannon et al. 2014). In this case, it may be more beneficial to use lure because even a marginal increase in daily detectability has a multiplicative increase on detectability throughout a survey (Garrard et al. 2008).

As the probability of detecting a species at least once increases with the number of visits (Garrard et al. 2008), it is theoretically possible to continue revisiting sites to detect any species so long as the species is present at a site. However, most occupancy models assume a species’ occupancy status does not change at a site over a survey season. Increasing the number of repeat visits could violate this assumption if a species colonizes or leaves a site over a survey season, resulting in biased occupancy estimates (Rota et al. 2009; Otto et al. 2013). To avoid violating the site closure assumption it may be more beneficial to increase species detectability rather than increase the number of repeat visits to a site. Our results illustrate that lure could increase the detectability of some species thereby making it possible to reduce the number of repeat visits to a site when lure is used. However, there are other options available to increase species detectability that should likely be explored. For example, placing multiple camera traps to monitor the occupancy status of a single site could increase species detectability by increasing the number of days sampled while keeping the overall survey season short to ensure closure (Stokeld et al. 2016).

In our study there was some evidence that cottontail were detected on fewer days at lured sites (Figure 2) and we observed that they were photographed 42% less often when lure was present (Figure 4). While lure may have encouraged avoidance behavior in this species, our study design cannot separate the potentially negative effect of lure from other causes. As lure increased visitation rates for some mesocarnivores, rabbits could instead be avoiding encounters with these species, which would result in fewer detections. Regardless of the causal pathway, it is important to consider that lure may have opposite the intended effect for prey species, especially if a survey is designed for predators (Rocha et al. 2016). Therefore, if the goals of a camera survey are to sample a wildlife community with predators and prey, it is critical to consider how lure may influence the resulting data.

It is possible we failed to observe a lure effect if our weekly visits inoculated these locations with novel human scents and therefore discouraged wildlife from investigating the area. We do not believe this occurred for several reasons. First, we used nitrile gloves when placing lures and cameras to not leave our scent behind. Second, the forest preserves throughout Chicago receive an estimated 40 million recreational visits each year (FPDCC 2019) and thus the environment is likely saturated with human-associated odors. It is highly likely that the species who reside within these natural areas are accustomed to the novel smells that humans may leave behind, and if so our infrequent visits likely had a negligible effect on the overall outcome of the study.

One aspect we did not include in this study was comparing our ‘non-lure control’ to another location with nothing in view of the camera (i.e., a true control). As the camera itself and the treatments placed are novel objects, species or individuals fearful of novel stimuli may have avoided the area entirely (Metler & Shivak 2007). Coyotes, for example, may be wary of camera traps (Séquin et al. 2003) and had the lowest detection probability in our study (Figure 2). Even though most urban species are bolder than their rural counterparts (Lowry et al. 2013; Breck et al. 2019), a number of steps could be taken to address the novelty aspect of a camera trap deployment. For example, future research could deploy cameras in advance of data collection to allow wildlife to acclimate and incorporate a ‘true’ control with the two treatments we used to differentiate the ‘pouch effect’ (visual attractant or deterrent) from the ‘lure effect’. Regardless, our results indicate that some species are seen more often when lure is present, and we recovered many images of species investigating the lure pouch throughout the study.

One potential criticism of luring camera traps is that lure may bring a species in from long distances to investigate an area they do not occupy. This would, in turn, generate false positives in the data leading to biased estimates of occupancy or abundance. While we do not think this is the case in our study, such implications are not likely universal. Many environmental factors, such as weather, the placement of trees, terrain, or humidity can either function as barriers to air flow or influence the movement of airborne molecules (Long et al. 2008). As we failed to detect a lure effect for many species, it could be that this lure 1) does not increase species detectability, 2) increases detectability by such a small amount we failed to detect it, or 3) has a large spatial ‘bleed over’ effect wherein the cameras that had lure during the third andfourth week of the study influenced detectability at cameras without. We do not believe it is the last possibility as a post-hoc reanalysis comparing the first week of ‘no lure’ sampling to the remaining weeks revealed similar results to what we report here (supp mater). Regardless, future research is necessary to determine the distance at which lure acts upon wildlife, which may require experimental manipulations with collared individuals.

In this paper, we used a tri-fold approach to quantify the effect of a common olfactory lure on detection rates of urban mammals while camera trapping. By doing so, we were able to better understand how wildlife respond to the presence of lure, which we could not have done by using a single metric. Our results show that lure may not be as beneficial as expected, in terms of increasing detectability, but the choice to use lure likely depend on several factors, including the density of the study species, and the dynamics between the species studied. When contemplating the use of lure in a camera trap study, the associated effects of lure on the species community should be carefully considered. As camera traps are an increasingly popular monitoring technique it is important to quantify how differences in study design may influence the resulting data. By doing so, much stronger inferences and cross-study syntheses can be made which will, in turn, improve ecological insight and wildlife conservation.

# Acknowledgements

We would like to thank T. Gallo for their insightful comments while we planned this study and M. Huck for assistance with field work. We would also like to thank N. Clemente and Pariveda Solutions for their help with an application to store and tag our camera trap images. We acknowledge our colleagues in the Operations and Development Departments at the Lincoln Park Zoo; their work behind the scenes is vital to our research. This work was supported by the Abra Prentice Foundation and the Davee Foundation.

# Data accessibility

Should this manuscript be accepted the data, R, and JAGS code will be archived in Dryad and the data DOI will be included at the end of the article.

# Author contributions

MF and SM developed the idea for the manuscript, while all authors contributed to the development of the study design. MF and GB collected the data. MF, GB, and EL identified camera trap photographs. MF and GB wrote the initial draft of the manuscript and all authors contributed to later drafts.

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