Wildlife Society Bulletin 1–10; 2020; DOI: 10.1002/wsb.1122

*Original Article*

# Effect of Lure on Detecting Mammals with Camera Traps

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**ABSTRACT** Motion-triggered camera traps are subject to imperfect detection and thus camera-trapping surveys often try to increase species detectability as part of the study design. One possible way to increase detectability is to use lures, which may encourage a species to investigate a given area. Yet the effectiveness of lures is primarily grounded in anecdotal support. We quantified the effect of a common olfactory carnivore lure on the detectability of mammals near Chicago, Illinois, USA, during 27 August 2018–25 September 2018. We deployed 2 camera traps per site, spaced apart by 100 m, to assess whether lure can modify detectability both within and between sites. At each camera location, we changed lure treatments every 7 days and placed either a lure or a non-lure control in view of each camera following a fully crossed design. For analysis, we developed single-season occupancy models with 3 distinct observational models to quantify whether lure increased the number of days a species was detected, decreased the amount of time to first detection, and increased the number of images collected. Lure induced a subtle change in detectability. Virginia opossum (*Didelphis virginiana*) responded most to the presence of lure; their daily detection probability rose by roughly 5% and the number of opossum images nearly doubled. However, the effect of lure was often negative for prey species. When lure was present, eastern cottontail (*Sylvilagus floridanus*) daily detection probability decreased by 5% and they were photographed 63% less often. Likewise, eastern gray squirrel (*Sciurus carolinensis*) arrived 70% later to a camera trap if lure was present and were photographed 14% less. By using multiple criteria, we were able to better understand how wildlife respond to lure while camera-trapping more thoroughly than would be possible with a single metric. Our results show that lure may not be as effective as expected in terms of increasing detectability, but the choice to use lure should depend on several factors, including the density of the study species, species life history, and the dynamics between the species studied. 

**KEY WORDS** camera-trapping, detection probability, lure, mammals, occupancy model, time-to-detection.

Motion-triggered camera traps have become a widely used tool for ecological research and are a common methodology for large-scale biodiversity monitoring projects (O'Connell et al. 2010, Steenweg et al. 2017, Magle et al. 2019). As an alternative to live-trapping, camera traps can passively sample over a large spatial extent and do not require the physical restraint of an organism, thereby eliminating 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 (O'Connell et al. 2010, Burton et al. 2015, MacKenzie et al. 2017). 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 et al. 2016, MacKenzie et al. 2017).

Camera traps are subject to imperfect detection wherein some species that are present in a sampled location are not detected (Burton et al. 2015). Imperfect detection may be partly addressed during data analysis (MacKenzie et al. 2017), but camera-trapping surveys may also investigate ways to increase species detectability as part of their study design (O'Connell et al. 2010, Hofmeester et al. 2019). The use of lures or bait has been suggested to increase species detectability (Long et al. 2012). The primary motivation for using lures or bait is that they engage a species' sense of smell, sight, or hearing and therefore increase the chance a target species investigates the area where a camera is deployed (Schlexer 2008). However, the reasoning behind the

Received: 6 May 2019; Accepted: 23 April 2020
Published:

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use of lures or bait is mostly grounded in anecdotal support (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, du Preez et al. 2014, Rocha et al. 2016, Suárez-Tangil and Rodríguez 2017). However, with 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) and local habitat conditions. Furthermore, most studies determine the effect of lure with a single metric—the number of days a species was detected in the presence or absence of lure (Burki et al. 2010, Gerber et al. 2012, Satterfield et al. 2017, Ferreras et al. 2018). Such analyses preclude other ways lure may influence species detectability, such as decreasing time to first detection (i.e., latency to detection; Bischof et al. 2014) or increasing the number of images collected (Rocha et al. 2016). Whereas these additional metrics may be interrelated (i.e., increasing the number of days a species is detected may result in a shorter time to first detection or increase the number of images collected), there is the possibility that species may respond differently across metrics. To better quantify a lure effect, it is critical that species abundances and detectability metrics be considered in both study design and analysis.

We used a multifaceted approach to quantify the effect of a common olfactory carnivore lure on the detectability of a suite of mammalian species in natural areas throughout Chicago, Illinois, USA. Our goals 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. It is possible that these 3 metrics are interrelated and a positive response to lure may result in a species being detected on more days, in less time, and result in more images, but this assumption has yet to be tested. By simultaneously quantifying the effect of lure with these metrics, we were able to determine exactly how interrelated such detection metrics may be across multiple species. We extend previous assessments by experimentally manipulating lure at pairs of cameras to test whether lure affected species detectability both within and among sites. Our approach allowed us to quantify whether lure increases the chances of detecting a species within a site because they may be attracted to a camera that has lure relative to a nearby camera that does not.

## STUDY AREA

Our study was conducted in northeastern Illinois within the Chicago metropolitan area. The third largest metropolitan area in the United States, the Chicago metropolitan area was located to the southwest of Lake Michigan and contained an estimated 9.9 million residents, 27% of which live within the city of Chicago itself (U.S. Census Bureau 2018). The Chicago metropolitan area receives a mean annual precipitation of 93.70 cm and experiences 4 distinct seasons that consist of intermediate springs ($\bar{x} = 9.22^\circ$ C) and autumns ($\bar{x} = 11.39^\circ$ C), warm summers ($\bar{x} = 22.11^\circ$ C), and cold winters ($\bar{x} = -3.11^\circ$ C; NOAA 2019). Average weekly precipitation and temperature during our study were respectively 3.16 cm (min = 0.00 cm, max = 8.64 cm) and 22.32° C (min = 17.8° C, max, 25.6° C; NCDC 2019). The region had relatively flat topography and an average elevation of roughly 180 m (WolframAlpha LLC 2019). Although predominately urban, natural areas throughout the Chicago metropolitan area consisted of tallgrass prairies, oak woodlands or savannas, and prairie meadows or wetlands (Wang and Moskovits 2001). We have observed 15 mammal species since 2011 through our camera-trapping research in this region (Table S1, available online in Supporting Information).

## METHODS

We randomly selected 20 locations within forest preserves southwest of downtown Chicago in DuPage and Cook counties (Fig. 1A). Each location (hereafter, sites) were constrained to be a minimum of 1 km apart from one another. Therefore, a given forest preserve could host multiple sites (Fig. 1B). We selected a distance of 1 km because it was greater than the home range radii of most urban-adapted medium- to large-sized mammals, except for the coyote (*Canis latrans*) and red fox (*Vulpes vulpes*; Feldhamer et al. 2003). We wore nitrile gloves when setting up and checking on sites to decrease the likelihood of imparting our scent to the local area. We selected forest preserves 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 represented the ideal green space to quantify the effect of lure on mammal detection probability as many species were likely present.

Each site consisted of 2 motion-triggered, infrared Bushnell TrophyCam (Bushnell Corporation, Overland Park, KS, USA) trail cameras (hereafter, camera traps) that were placed in areas with relatively low amounts of understory vegetation to reduce the likelihood of a camera trap being triggered by wind-blown vegetation (Fig. S2.1 through S2.20, available online in Supporting Information). After placing the first camera trap as close as possible to the randomly selected point for that site, we walked 100 m in a random direction to set the second camera trap. We selected this distance because it is less than the home range radii of most urban-adapted medium to large sized mammals (Feldhamer et al. 2003). Thus, for most species in our study area, sites separated by >1 km were likely independent whereas the 2 camera traps within a site are not. Camera traps were not placed along apparent game trails. We left camera traps at their factory-default sensitivity and set to take a single photo with a 30-second delay between capture events so long as it was being triggered (Table S3, available online in Supporting Information). We placed camera traps inside a metal security box, strapped to a tree roughly 130 cm from the ground, and cable locked. Camera traps

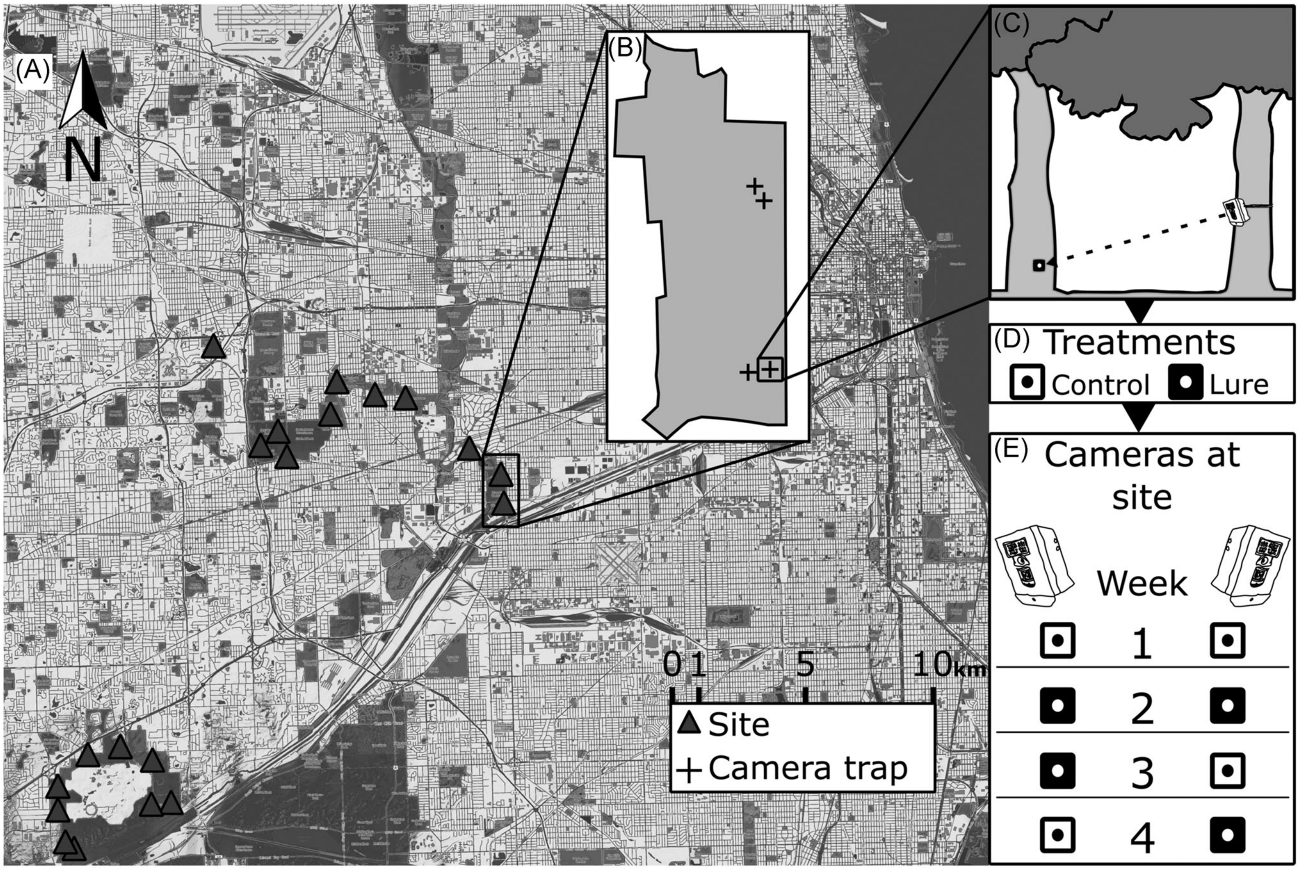


**Figure 1.** Twenty sites were selected inside forest preserves to the southwest of downtown Chicago, Illinois, USA, to study the effect of lures on mammal detectability using camera traps during 2018 (A). Each site consisted of 2 camera traps separated by 100 m (B). Each camera trap was strapped to a tree and pointed in a downward trajectory (C) toward a lure or non-lure control (D). During each week of the 4-week study a different combination of lure or nonlure control was placed in view of the 2 camera traps within a site following a fully crossed design (E).

were then angled at a downward trajectory by placing sticks between the tree and top of the camera trap to center the camera's field of view on a given experimental treatment, which was located roughly 2.5–5.8 m from the camera trap on another tree (mean distance between camera trap and treatment = 3.91 m, SD = 0.73; Fig. 1C). Therefore, sites in our study can be interpreted as the local area around the 100-m pair of camera traps, which we assumed equal among sites. We believe this assumption was reasonable because there were no physical barriers that limited animal movement at each site.

We had 2 treatments for our study, a lure treatment and a non-lure control (Fig. 1D). 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, ID, USA]). Fatty acid scent disks are a commonly used olfactory lure suggested to increase the detectability of mesocarnivores, especially coyote (Roughton and Sweeny 1982, Suárez-Tangil and Rodríguez 2017). The non-lure control was a piece of white cardstock cut to an identical size to that of the FAS disk. Treatments were contained within a 7.5-cm × 7.5-cm black mesh pouch and nailed to a tree approximately 30 cm from the ground (Fig. S4.1 and S4.2, available online in Supporting Information). The non-lure cardstock and mesh control was used to account for the placement of a novel object in view of a camera trap when using lure (i.e., a visual control).

We deployed camera traps for 28 consecutive days between 27 August 2018 and 25 September 2018. This 28-day primary sampling season was divided into 4 1-week-long secondary sampling sessions. For each site of 2 camera traps, we changed treatments every week following a fully crossed design (Fig. 1E). Briefly, for camera traps A and B in a site, both received non-lure controls on week 1, which we exchanged for lure pouches on week 2. On week 3, camera trap A received a new lure pouch while camera trap B was given a non-lure control. The opposite occurred for week 4: camera trap A received a non-lure control while camera trap B received a lure pouch (Fig. 1E). We replaced memory cards every week and replaced batteries on all camera traps at the beginning of week 3 (or as needed otherwise during weekly checks). To ensure accurate species identification in an image, pictures were identified twice by separate individuals (GB and MF). We marked infra-red images of tree squirrels ($n = 603$) as a black and white squirrel and censored them from subsequent analyses because the individual within a photo could have either been an eastern gray squirrel (*Sciurus carolinensis*) or fox squirrel (*S. niger*). We identified color images of tree squirrels to the species level. If there was disagreement between identifications or counts of individuals on an image, author EL or MF assessed the photo for a third time to provide final judgement on the identification. We programmatically collected the date and time for each image from its exchangeable image file format (exif) metadata. This study was approved by the Lincoln Park Zoo Research Committee (2009-028). Our internal Institutional Animal Care and Use Committee deemed this exempt from full committee review because of the noninvasive nature of our study.

**Statistical Analysis**

We fit 3 separate Bayesian hierarchical occupancy models to all species with sufficient data. For simplicity, we explain these models for a single species. In the 3 models, we assume the occupancy status of a species does not change over the 28-day primary sampling period and that the probability of occupancy does not vary between sites. Thus, the probability of occupancy, $\psi$, at $s$ in $1,\ldots,S$ sites is assumed to follow a Bernoulli process:

$$z_s \sim \text{Bernoulli}(\psi)$$

where $z_s$ is a random binary variable that represents the occupancy status of a site by the species. If the species is present, $z_s$ takes the value of 1 and is otherwise 0. Such a model is no different from 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 (MacKenzie et al. 2017). All 3 models use the same specification of the latent occupancy state and therefore provide their own occupancy estimates.

*Observation model 1: does lure increase the number of days a species is detected?*—Our first model assumed that days within a sampling week are repeat independent surveys in which a species may be detected given its presence. This is the most traditional formulation of a hierarchical occupancy model (Kéry and Royle 2015). After assuming a Bernoulli process for the latent occupancy state (i.e., $z_s \sim \text{Bernoulli}(\psi)$), for each of the 2 $c$ camera traps deployed at a site and $k$ in 1–4 weeks of sampling we can model the effect of lure as the following binomial process:

$$y_{s,k,c} \mid z_s \sim \text{Binomial}(j_{s,k}, p_{s,k,c} \times z_s)$$

where $y_{s,k,c}$ is the number of days a species was detected at site $s$ on week $k$ at camera trap $c$, $j_{s,k}$ is the number of days sampled at site $s$ on week $k$, and $p_{s,k,c}$ is the probability of detecting a species given its presence (i.e., $z_s = 1$). We incorporate the presence of lure on species detectability via the logit-link function:

$$\text{logit}(p_{s,k,c}) = a_0 + a_{lure} x_{s,k,c} + a_{precip} w_{s,k} + \mu_s.$$

Here, $a_0$ is the log odds a species is detected without lure given no precipitation over a week, $a_{lure}$ is the log odds difference in detection given the presence of lure, and $a_{precip}$ is the log odds difference in detection given a 2.54-cm increase in precipitation over a week of sampling, and $\mu_s$ is a sampling-location-level random effect to account for variability in detection rates that may exist between sites not attributed to lure or precipitation (e.g., abundance). We included the $a_{precip}$ parameter in this model because of scattered thunderstorms that occurred during some weeks of the study, which likely influenced species activity and therefore their detectability (high = 20.32 cm during week 1, low = 0.00 cm during week 3). We chose to include precipitation instead of sampling week or Julian day because the overall sampling window was short relative to the average life span of the species in our study area (Feldhamer et al. 2003); thus, we predicted that precipitation would have a stronger influence on species activity, and precipitation was highly correlated to sampling week (Spearman's rho = −0.94). For the remaining variables, $x_{s,k,c}$ is an indicator variable, which takes the value 1 when lure is present at a camera trap, and $w_{s,k}$ is the inches of rainfall during a week. We collected precipitation data from the O'Hare International Airport meteorological weather station in northwest Chicago (NCDC 2019).

*Observation model 2: does lure decrease the amount of time to first detection?*—In addition to increasing the number of days during which a species investigates the location a camera trap 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 again assume a Bernoulli process for the latent occupancy state (i.e., $z_s \sim \text{Bernoulli}(\psi)$) but treat data collection as a continuous time process for the observation model. Let the response variable of the observation model, $q_{s,k,c}$, 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 trap each week). If a species is present at a site but not detected after 7 days when treatments are changed it is unknown how long it would take for the species to be photographed. To account for this, we modeled $q_{s,k,c}$ 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., $Tmax = 7$ days). Following Kéry and Royle (2015), the continuous time-to-detection observation model is

$$d_{s,k,c} = z_s \times I(q_{s,k,c} > Tmax_{s,k,c}) + (1 - z_s)$$

$$q_{s,k,c} \mid z_s \sim \text{Exponential}\ (\gamma_{s,k,c}) \qquad \text{if} \quad d_{s,k,c} = 0$$

$$q_{s,k,c} = NA \qquad \text{if} \quad d_{s,k,c} = 1$$

Here, $I(q_{s,k,c} > Tmax_{s,k,c})$ is an indicator function that takes the value 1 if a species is present but not detected in a given week at a camera trap. With this specification, $d_{s,k,c}$ equals 1 if a species is present, but went undetected or if they were not present (i.e., $z_s = 0$). When this occurs, $q_{s,k,c} = NA$. Otherwise, $d_{s,k,c}$ equals 0 and we sampled from the exponential distribution to estimate the inverse scale parameter $\gamma_{s,k,c}$ from the right-censored data. To estimate the effect of lure on this parameter, we used the log-link function

$$\log(\gamma_{s,k,c}) = b_0 + b_{lure} x_{s,k,c} + b_{precip} w_{s,k} + \mu_s.$$

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

*Observation model 3: 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 trap 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, after assuming a Bernoulli process for the latent occupancy state (i.e., $z_s \sim \text{Bernoulli}(\psi)$), let $v_{s,k,c}$ be the number of images collected of a species as site $s$, week $k$, and camera trap $c$. We modeled the number of images collected as the following Poisson process:

$$v_{s,k,c} \mid z_s \sim \text{Poisson}(z_s \times Tmax_{s,k,c} \times \lambda_{s,k,c})$$

where $z_s$ and $Tmax_{s,k,c}$ are the same as before while $\lambda_{s,k,c}$ is a rate parameter that estimates the average number of photos expected per day given a species' presence. Like model 2, $Tmax_{s,k,c}$ 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 used the log-link, as we did with model 2:

$$\log(\lambda_{s,k,c}) = d_0 + d_{lure} x_{s,k,c} + d_{precip} w_{s,k} + \mu_s.$$

*Specification of priors and model fitting*—We used a Bayesian approach to parameterize our models. For all models, we used an uninformative Beta(1,1) prior for the probability of occupancy, $\psi$. For the observational process of each model the choice of priors depended on the link function. For model one, which used the logit-link, we followed the suggestions of Gelman et al. (2008) and gave the intercept, $a_0$, a Cauchy (0, 10) prior while the slope parameters ($a_{lure}$ and $a_{precip}$) received Cauchy (0, 2.5) priors. For models 2 and 3, the log-link intercept, lure effect, and precipitation parameters received uninformative Normal (0, $\sigma = 10{,}000$) priors. Finally, random effects from all models were drawn from Normal (0, $\sigma$) distributions where $\sigma \sim \text{Gamma}(1{,}000, 1{,}000)$.

We executed models 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, we sampled parameters 300,000 times across 6 chains. We thinned Markov chain Monte Carlo chains by 5. We assessed model convergence by visually inspecting trace plots and ensuring that Gelman–Rubin diagnostics for each parameter were <1.10 (Gelman et al. 2014). We calculated evidence of an effect for estimated regression coefficients by determining the probability a posterior was greater than or less than zero, depending on the direction of the effect. In addition, we calculated 95% Bayesian credible intervals (hereafter, 95% CI) from the posterior of the parameters.

## RESULTS

Camera traps were functional for 1,110 days out of a possible total of 1,120 (28 days × 40 camera traps). We collected 11,050 images, and GB and MF agreed on 93% of image classifications. Twelve species of mammals were identified, and 55.29% of images included mammals or birds. Eight mammals had sufficient data for the 3 models to converge: coyote (123 photos across 17 sites), eastern chipmunk (*Tamias striatus*, 359 photos across 15 sites), eastern cottontail rabbit (*Sylvilagus floridanus* [hereafter, cottontail], 70 photos across 9 sites), eastern gray squirrel (1,890 photos across 20 sites), fox squirrel (458 photos across 17 sites), raccoon (*Procyon lotor*, 1,497 photos across 20 sites), Virginia opossum (*Didelphis virginiana* [hereafter, opossum], 396 photos across 20 sites) and white-tailed deer (*Odocoileus virginianus* [hereafter, deer], 1,038 photos across 20 sites). The remaining 4 species that had insufficient data were the American mink (*Neovison vison*, 3 photos at 1 site), long-tailed weasel (*Mustela frenata*, 1 photo at 1 site), southern flying squirrel (*Glaucomys volans*, 7 photos across 2 sites), and striped skunk (*Mephitis mephitis*, 13 photos across 8 sites).

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

Independent of the potential effects of lure, daily detection probability as estimated by the first model varied greatly among species (Fig. 2). Coyote, for example, exhibited a 5.19% (95% CI = 2.59–9.51) probability of being detected each day, which did not increase when lure was placed in front of a camera trap (Fig. 2). Raccoon and gray squirrel had the greatest daily detection probabilities without lure, which were 51.82% (95% CI = 42.61–61.42) and 56.44% (95% CI = 43.93–61.42), respectively. The presence of lure decreased cottontail detection probability from 10.53% (95% CI = 1.10–20.05) to 5.45% (95% CI = 0.49–10.70), and 98.65% of the posterior for $a_{lure,cottontail}$ was less than 0 ($a_{lure,cottontail} = -0.71$; 95% CI = −1.40 to −0.06).

There was some evidence that the presence of lure increased opossum daily detection probability by roughly 5%, and 96.98% of the posterior for $a_{lure,opossum}$ was greater than zero ($a_{lure,opossum} = 0.28$; 95% CI = −0.01 to 0.59). The presence of lure also decreased fox and gray squirrel detection by about 3.5%, but we are only about 84% certain of the direction of this effect given their posteriors (Fig. 2). There was little evidence that the presence of lure increased or decreased coyote and raccoon daily detection

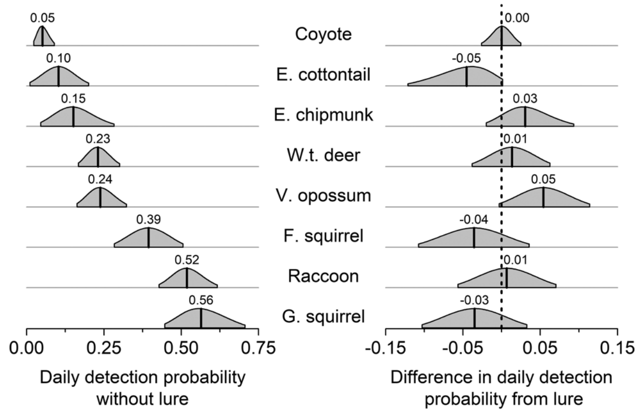


**Figure 2.** Lure had a marginal, but varying effect on the number of days species were detected inside forest preserves to the southwest of downtown Chicago, Illinois, USA, during 2018. The left plot illustrates the daily probability of detecting a species when no lure was in front of a camera trap. The right plot illustrates the additive change in a species detection probability 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. Median estimates are labeled above their respective posterior distribution. The vertical dotted line at 0 is for reference, an estimated difference of 0 would indicate no change in a species daily detection probability given the presence of lure.

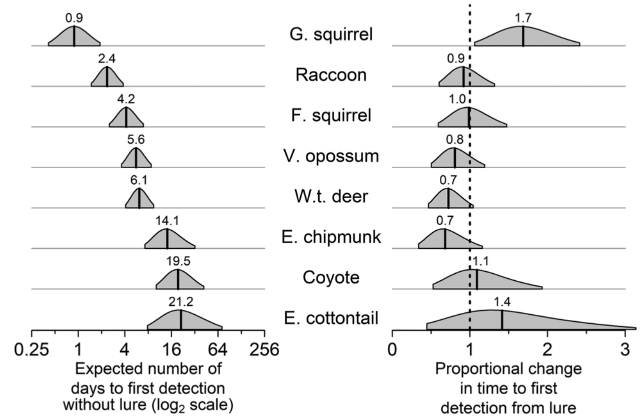


**Figure 3.** Gray squirrel was the only species to be photographed later when lure was placed in front of a camera trap inside forest preserves to the southwest of downtown Chicago, Illinois, USA, during 2018. The left plot is the expected number of days until the first photograph is taken, given the 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 <1 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. Median estimates are labeled above their respective posterior distribution. The vertical dotted line at 1 is for reference, an estimated proportional change of 1 indicates no difference in time to detection given the presence of lure.

probabilities. Weekly precipitation had a negative influence on the daily detection of most species save for cottontail, for whom we did not find evidence of an effect (Table 1). Deer were observed on more days during weeks with greater amounts of precipitation (Table 1).

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

Without lure, the expected number of days to first detection as estimated by the second model ranged from 0.89 days (95% CI = 0.33–1.74) for gray squirrel to 21.20 days (95% CI = 5.51–72.28) for cottontail (Fig. 3). With lure, gray squirrel were observed 70.12% later (95% CI = 8.16–144.30). There was a general decrease in the amount of time to first detection for raccoon, deer, chipmunk, and opossum when lure was present (i.e., were photographed for the first time in less days; Fig. 3). Of these species, we were most certain that lure decreased the time to first detection for deer because 94.43% of the posterior for $b_{lure,deer}$ was greater than zero, followed by the chipmunk (89.64% certain), opossum (83.31% certain), and the raccoon (65.86% certain, Fig. 3). There was some indication that it took longer to detect coyote and cottontail given the presence of lure, but evidence of this effect was weak (Fig. 3). Weekly precipitation decreased the amount of time it took to detect fox squirrel, gray squirrel, raccoon, and opossum, whereas the time to detect deer increased (Table 1).

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

We are 100% certain that 2 species had more photos taken when lure was present—opossum and deer—their entire $d_{lure}$ posterior estimates from the third model were greater than zero (Fig. 4). For opossum, the number of images captured increased by a factor of 1.73 (95% CI = 1.38–2.13), whereas the number of images captured of deer increased by a factor of 1.47 (95% CI = 1.26–1.69). Cottontail and gray squirrel were photographed less often given the presence of lure—the number of images collected decreased by 62.98% (95% CI = 40.76–80.11) and 14.06% (95% CI = 6.18–21.86), respectively. We are 100% and 99.94% certain, respectively, of

**Table 1.** The median estimated effect of precipitation on the probability of daily detection, time to first detection, and the number of images taken within 1 week estimated from 3 occupancy models fit to species detection versus nondetection data in northeastern Illinois, USA, during 2018. Regression coefficients for the probability of daily detection ($a_{precip}$) are on the logit scale whereas the remaining coefficients ($b_{precip}$ and $c_{precip}$) are on the log scale. Median estimates and 95% credible intervals (CI) are provided.

| | Probability of daily detection | | Time to first detection | | No. of images collected | |
|---|---|---|---|---|---|---|
| Species | $a_{precip}$ | 95% CI | $b_{precip}$ | 95% CI | $d_{precip}$ | 95% CI |
| Coyote | 0.02 | −0.05, 0.09 | 0.02 | −0.01, 0.10 | 0.03 | −0.02, 0.09 |
| Eastern chipmunk | −0.11 | −0.17, −0.05 | −0.06 | −0.16, 0.03 | −0.10 | −0.14, −0.07 |
| Eastern cottontail | −0.06 | −0.15, 0.04 | −0.02 | −0.14, 0.10 | −0.06 | −0.13, 0.00 |
| E. gray squirrel | −0.15 | −0.19, −0.11 | −0.18 | −0.24, −0.12 | −0.11 | −0.12, −0.09 |
| Fox squirrel | −0.22 | −0.28, −0.17 | −0.16 | −0.23, −0.08 | −0.16 | −0.19, −0.13 |
| Raccoon | −0.09 | −0.12, −0.05 | −0.06 | −0.11, 0.00 | −0.04 | −0.05, −0.02 |
| Virginia opossum | −0.11 | −0.16, −0.07 | −0.11 | −0.17, −0.04 | −0.08 | −0.11, −0.04 |
| White-tailed deer | 0.08 | 0.04, 0.12 | 0.11 | 0.06, 0.16 | 0.10 | 0.08, 0.12 |

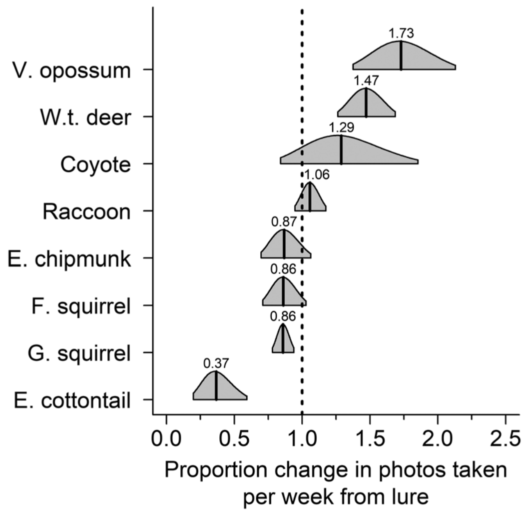


**Figure 4.** More images were collected of opossum and white-tailed deer while lure was present, whereas cottontail rabbits and gray squirrels were photographed less inside forest preserves to the southwest of downtown Chicago, Illinois, USA, during 2018. The x-axis represents the proportional change in the number of photos taken of a species when lure was present. Values >1 indicate that more images were taken. Vertical solid lines are median estimates, which are plotted with the posterior distribution that fell within its associated 95% credible interval. Median estimates are labeled above their respective posterior distribution. The vertical dotted line at 1 is for reference, an estimated proportional change of 1 indicates no difference in the number of images taken given the presence of lure.

the direction of this effect given the $d_{lure}$ posterior estimates for the cottontail and gray squirrel. There was some evidence the number of coyote photos increased given the presence of lure, but we are only 90.42% certain of the direction of this effect (Fig. 4). Likewise, there was some evidence that chipmunk (90.52% certain) and fox squirrel (94.26% certain) were photographed less often (Fig. 4). Squirrels, chipmunk, opossum, cottontail, and raccoon were photographed less often on weeks with more precipitation whereas deer were photographed more often (Table 1).

### Occupancy estimates across models

After averaging occupancy estimates across all 3 models, raccoon and deer were tied for largest estimated site occupancy at 96.76% (95% CI = 86.74–100.00), followed by the eastern gray squirrel (96.75%, 95% CI = 86.68–1.00), opossum (96.75%, 95% CI = 86.75–1.00), coyote (90.34%, 95% CI = 73.34–1.00), fox squirrel (83.35%, 95% CI = 66.17–96.66), eastern chipmunk (78.82%, 95% CI = 59.25–99.39), and cottontail (55.30%, 95% CI = 28.93–93.65). Within species, differences in occupancy estimates between models were small, though were larger for less common species. The coyote, eastern chipmunk, and cottontail were the only species where between-model occupancy estimates potentially differed by >1.00% (0.53 [95% CI = 0.02–1.11], 1.21 [95% CI = 0.19–2.04], and 6.52 [1.52–17.89], respectively).

## DISCUSSION

Our threefold approach to quantify the effect of an olfactory lure on urban mammals offers evidence that the presence of lure may induce, at best, a subtle increase in detectability for some species. On the other hand, we found that placing FAS disks in view of a camera trap may also be correlated with a decrease in detections of fox squirrel, gray squirrel, and cottontail. We found some evidence of an increase in detection probability for only one mesocarnivore—the opossum. When lure was in view of a camera, opossum were detected across more days of a survey, in a shorter amount of time, and the number of opossum images nearly doubled. Conversely, raccoon and coyote showed little evidence of a lure response. Together, these findings indicate that lure could provide some increase in species detectability, but the effect of lure likely varies by species and may not be substantial. Given the 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, logistical constraints, and the time of year camera traps are deployed (Long et al. 2012). In our study area, lure may not be necessary to detect these urban species because they are common and abundant throughout the Chicago metropolitan area (Gallo et al. 2017). Detectability is partially a function of abundance (McCarthy et al. 2013); therefore, lure may not be as needed in studies of common species because detection probabilities are relatively large. Conversely, studies that focus on rare species, such as large terrestrial carnivores, require much more sampling effort per successful detection (MacKenzie and 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 over the entire sampling period (Garrard et al. 2008).

The probability of detecting a species at least once increases with the number of site surveys (Garrard et al. 2008). Thus, it is theoretically possible to continue surveying a site to detect a rare species so long as the species is present. However, most occupancy models assume closure, meaning a species' occupancy status does not change at a site over a survey season. For camera traps and other passive sampling methods, increasing the number of repeat surveys generally means increasing the number of days sampled. Increasing the number of days sampled could violate the closure 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 closure assumption, it may be more beneficial to increase species detectability rather than increase the number of surveys. Our results illustrate that lure could increase the detectability of some species, making it possible to reduce the number of surveys if lure is used. However, there are other field protocols 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 trap days sampled while keeping the overall survey season short to ensure closure (Stokeld et al. 2016). However, while such a field protocol may increase detectability, it could come at the cost of decreasing the number of spatial units sampled and therefore decrease statistical power for the latent state of an occupancy model, which is generally of more interest. As always, it is important to consider the possible trade-offs between the number of sites to sample and number of surveys to conduct (MacKenzie et al. 2017).

We found evidence that cottontails were detected on fewer days at lured camera traps and observed that they were photographed 63% less often when lure was present. Likewise, it took longer to detect gray squirrels when lure was present, and there was some evidence that squirrels and chipmunks were photographed less at lured camera traps. Lure may have encouraged avoidance behavior in these species, but our study design cannot separate the potentially negative effect of lure from other causes. Lure increased visitation rates for some mesocarnivores, so 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 goals of a camera trap survey are to sample a wildlife community with predators and prey, it is critical to consider how lure may influence the resulting data, especially when using lures such as FAS disks that were primarily created to attract carnivores (Roughton and Sweeny 1982).

Although not an intended goal of this study, our results highlight that lure can result in trade-offs in species detectability. Therefore, there are likely conditions when lure should or should not be used, especially when designing multispecies studies. Overall, we suggest that it is best to maximize detectability of the least-detectable species even if it comes at the cost of reducing detectability of the most-detectable species. Lure could be used if there is reason to believe it achieves this outcome. Conversely, if it is possible that lure decreases the detectability of species that are already rare then it should be avoided. If it is not possible to conduct a similar study to determine the influence of lure on the detectability of species in a region, previous research may report estimated detection probabilities for these species. An approximate lure effect could then be added or subtracted from the estimates. Our results indicate that an approximate lure effect is 2.75%, which is the median difference in daily detection probability from lure across the species we studied. Simulations of varying study designs could then be explored to determine whether lure should be used (Latif et al. 2018).

Our results indicate that the degree of interrelation among detection metrics is species-dependent. For example, results across metrics were interrelated for opossum but different for the eastern chipmunk and deer. Deer, for example, were not detected on more days but more photos were collected given the presence of lure. It could be that deer visited a camera once, or in similar proportion to non-lured camera traps, but stayed longer to investigate the lure when it was present. Fitting these 3 observation models to camera trap data only requires different summaries of the data, so the additional labor to estimate these effects is minimal. We did, however, observe small differences in occupancy estimates between the 3 observation models, which was greater for species detected at fewer sites. Thus, care should be taken when altering the mean structure of a model because estimates of the latent occupancy state may differ.

It is possible we failed to observe a lure effect if our weekly visits introduced novel human scents to the locations 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 camera traps to reduce the amount of human scent imparted on the equipment. Second, the forest preserves throughout Chicago receive an estimated 40 million recreational visits each year, and thus the environment is likely saturated with human-associated odors (FPDCC 2019). 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 trap (i.e., a true control). The camera trap itself and the treatments placed are novel objects, so species or individuals fearful of novel stimuli may have avoided the area entirely (Mettler and Shivik 2007). Coyotes, for example, may be wary of camera traps and had the lowest detection probability in our study (Séquin et al. 2003). Even though most urban species are bolder than their non-urban counterparts (Lowry et al. 2013, Breck et al. 2019), several steps could be taken to address the novelty aspect of a camera trap deployment. For example, camera traps could be deployed in advance of data collection to allow wildlife to acclimate and incorporate a true control with the 2 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.

A potential criticism of using lure with camera traps is that lure may attract a species from long distances to investigate an area that they do not typically occupy. This would, in turn, generate false positives in the data, leading to biased estimates of occupancy or abundance. However, there are many environmental factors—such as weather, placement of trees, terrain, or humidity—that can function as barriers to air flow or influence the movement of airborne molecules (Long et al. 2012). The spatial extent of a lure is therefore likely dependent on the environmental and topographical conditions it is placed within. Further, we failed to detect a lure effect for many species; therefore, it could be that this lure 1) does not increase species detectability, 2) increases detectability by such a small amount that we failed to detect it, 3) has a large spatial bleed over effect wherein the camera traps that had lure during the third and fourth week of the study influenced detectability at camera traps without, or 4) has a residual temporal effect wherein the lure still has an influence on species detectability after being removed from a camera trap. We are doubtful of the third possibility given that trained detection dogs can recognize target odors up to 63 m (Cablk et al. 2008). Given their predatory role, coyotes likely have similar olfactory limits and more advanced olfactory systems than herbivores (Kavoi and Jameela 2011). We are also doubtful of the fourth possibility given that the lure used was a plaster disk, which (unlike a liquid lure) can be easily removed from a location, and the scent is thus unlikely to linger for long periods. Regardless, it is likely that habitat heterogeneity has a stronger influence on the behavior of a species than lure, making it even less likely that the presence of lure may draw in animals from far distances (Stewart et al. 2019).

## MANAGEMENT IMPLICATIONS

We used 3 criteria to quantify the effect of a common olfactory lure on detection rates of urban mammals while camera-trapping. Our results show that lure can increase the detectability of some species, but it may come at the cost of decreasing the detectability of other species. Therefore, the choice to use lure likely depends on several factors, including the density of the study species, interspecies dynamics, habitat heterogeneity, and types of lures available. Camera traps are an increasingly popular monitoring technique, so 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.

## ACKNOWLEDGMENTS

We thank T. Gallo for his insightful comments while we planned this study, M. Huck for assistance with field work. We are grateful to L. McDonald (Associate Editor), J. Wallace (Editorial Assistant), F. Stewart and two other anonymous reviewers for their critical reviews and suggestions, which greatly improved the manuscript. 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. All code and data for this manuscript are located at www.github.com/mfidino/lure_project.

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*Associate Editor: L. McDonald.*

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