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Short Communication

Mammalian scent lures fail to increase detections of invasive Burmese pythons (*Python bivittatus*)

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Abstract

Burmese pythons (*Python bivittatus*) are large constricting snakes native to Southeast Asia that have invaded the Greater Everglades Ecosystem in South Florida, USA. Pythons have caused precipitous declines in native mammals and are exceedingly difficult to detect using traditional methods such as scout snakes, detection dogs, and visual surveys. Live mammal lures have previously been used to attract pythons, with rabbits outperforming rodents in increasing detection. While live mammal lures can increase python detection and identify hotspots of python activity, ensuring animal welfare and logistical challenges limit their utility. As part of this study, field experiments were conducted to determine if mammalian lures, derived from rabbits (feces, urine, and hair) could replace live mammals and increase the detection of pythons. We ran trials for 84 days from June to September 2022 for 21 paired plots across three study sites in the Greater Everglades. We monitored two groups, the treatment (i.e., rabbit scent) and control (i.e., soil) with camera traps on a 1-minute time lapse. We detected 11 pythons during our study, but there was no difference between controls with soil (n = 7) and treatments (n = 4). However, we did find that scent lures increased native snake detection. This pattern was best explained by an increased number of rodents at the scent lures. Our experiment indicates that mammalian scent lures alone are insufficient to attract pythons. Since live mammals can attract pythons, but scent lures cannot, future studies could examine if a multi-faceted lure combining several stimuli (i.e., heat, visual, movement) might increase python detection.

Key words: lure, treatment, Burmese python, snake, Everglades

Introduction

Invasive species are a dominant driver of species loss and environmental degradation (Vitousek et al. 1997; Simberloff et al. 2013). Invasive predators, in particular, can drastically reduce native vertebrate populations and communities as well as disturb ecosystem processes (Doherty et al. 2016; Rogers et al. 2017). Due to their ability to threaten and even extirpate native species, controlling invasive predators is often a primary concern for natural resource managers. However, managing invasive species is often difficult and costly (Bogich et al. 2008; Simberloff et al. 2013; Cuthbert et al. 2021). These challenges can be exacerbated when invasive species are hard

to detect (Zavaleta et al. 2001; Mehta et al. 2007). A species may go undetected due to cryptic coloration, use of inaccessible habitats, or inherent rarity (Steen 2010; Durso et al. 2011). Furthermore, once an invasive species is established, the resources required for effective management and control are often insufficient to keep pace with its spread and impacts (Hulme 2006; Reaser et al. 2020), making rapid and reliable early detection methods of paramount importance. It is through the advancement and refinement of research methodologies that we have the best chance of detecting cryptic species (Gompper et al. 2006; Long et al. 2007).

The Burmese python *Python bivittatus* (Kuhl, 1820, hereafter: python) is a large (> 50 kg), nonvenomous, constricting snake native to Southeast Asia (Barker and Barker 2008; Reed and Rodda 2009; Guzy et al. 2023). In the 1980s, pythons were introduced into the Greater Everglades Ecosystem (hereafter: the Everglades), a vast (> 10,000 km^2) and globally important wetland in South Florida, USA (Willson et al. 2011; Lodge 2016). This invasive predator has since established breeding populations extending 200 km from the Florida Keys to Lake Okeechobee (Figure 1; Willson et al. 2011; Dorcas et al. 2017; Hanslowe et al. 2018), and caused precipitous declines in mesomammal diversity (McCleery et al. 2015; Reichert et al. 2017; Soto-Shoender et al. 2020, Taillie et al. 2021). Despite control efforts, python populations appear to be increasing across the Everglades (Guzy et al. 2023). One of the main challenges in managing pythons in the Everglades is that they are exceedingly difficult to detect (Guzy et al. 2023).

While several approaches, including scout snakes (previously "Judas snakes" [Smith et al. 2016], with terminology modified by Fitzgerald et al. 2021), detection dogs (Romagosa et al. 2011), and visual surveys (Nafus et al. 2020), have been used to detect pythons, they have failed to provide a scalable solution (Guzy et al. 2023). More recently, McCampbell et al. (2024) showed that time-lapse camera traps (i.e., capturing images at predetermined intervals; Welbourne et al. 2017; Neuharth et al. 2020; Cove et al. 2023) coupled with live mammalian lures (i.e., domestic rabbits [*Oryctolagus cuniculus*]) can aggregate pythons, making it easier to detect and potentially capture them in localized areas. The time-lapse feature on cameras is necessary because snakes rarely emit enough heat or move enough to trigger the camera's sensors (Hobbs and Brehme 2017; Yackel Adams et al. 2019). Using camera traps paired with effective lures, such as rabbits, can offer managers detailed insights into the spatial and temporal patterns of python activity, enabling them to better target and assess removal efforts (McLean et al. 2017). However, like other python detection approaches, the use of domestic rabbits is costly, labor-intensive (requiring daily checks), and presents significant logistical challenges, particularly in remote areas with extreme conditions (i.e., hot, humid conditions with frequent storms). Thus, coupling the two methodologies could be a valuable approach to improve detection of pythons.

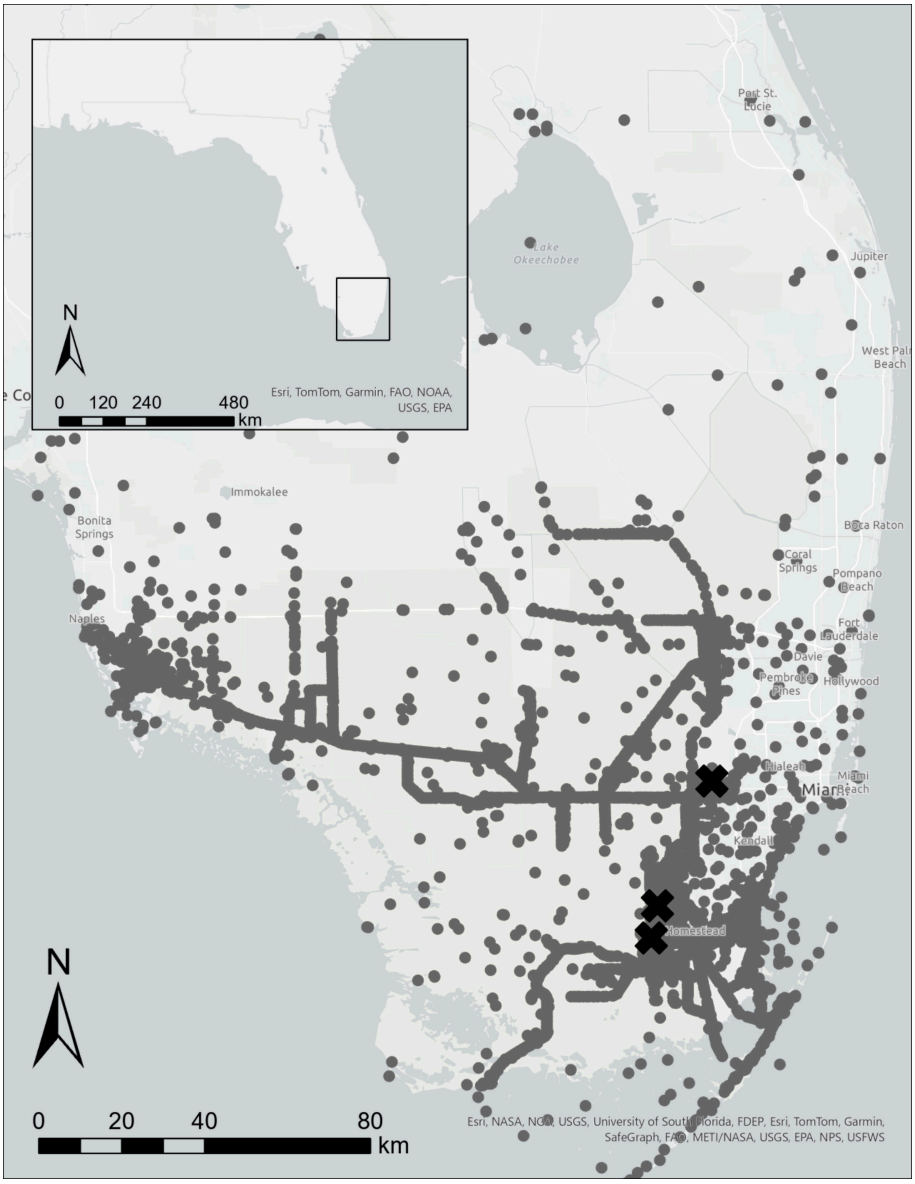

Figure 1. Locations of study sites across Miami-Dade County in South Florida, United States. Gray dots represent Burmese python detections reported to the Early Detection & Distribution Mapping System (EDDMapS 2024) from 1979 to April 2024. Black crosses represent our study sites from south to north: Frog Pond Public Small Game Hunting Area, Rocky Glades Public Small Game Hunting Area, and C-4 Impoundment.

Accordingly, there is a need to find cost-effective lures that attract pythons into the camera frame (Lindberg et al. 2000; Schlexer 2008). While snakes are attracted to movement (visual and vibrations; Haverly and Kardong 1996), and heat (infrared; De Cock Buning 1983), they appear especially sensitive to scent lures (Burghardt et al. 1988; Clark 2004; Baeckens et al. 2017) which they detect using nasal receptors (Byerly et al. 2010) and vomerolfaction (Cooper and Burghardt 1990; McCleery et al. 2015). For example, with Cornsnakes (*Pantherophis guttatus*), scent lures (soiled mouse bedding) were just as effective as live mouse lures in an experimental setup (Worthington-Hill et al. 2014). Yet, little research to date in the Everglades has examined how pythons respond to these types of mammalian scent lures (Guzy et al. 2023).

The goal of our study was to determine if scents from live rabbits (i.e., feces, urine, hair) could improve the detection of pythons and native snakes. This scent lure may work directly by attracting snakes or indirectly by aggregating rodents that are drawn to rabbit fecal matter (Otto et al. 2015), which in turn attract the snakes. To determine if mammalian scent lures could increase the detection of pythons and other snakes in the Everglades community (i.e., native snakes), we conducted a paired field experiment. We predicted that using scents derived from domestic rabbits along with time-lapse enabled cameras would increase our probability of detecting pythons. We also predicted that native snake detections would increase because of the aggregation of rodents and not the lure directly as native snakes in the Everglades rarely consume rabbits (McCleery et al. 2015).

Materials and methods

Study area

The Everglades in south Florida, USA, is the world's largest sawgrass prairie, encompassing over 10,000 km^2 (Lodge 2016). This subtropical wetland hosts more than 60 threatened and endangered plants and animals and is listed as a Wetland of International Importance in the Ramsar Convention (Brown et al. 2006; Richardson 2010). The Everglades vegetation communities comprise wet grass prairies interspersed with tree islands and hardwood hammocks. The prairie communities are dominated by sawgrass (*Cladium jamaicense*), muhly grass (*Muhlenbergia sericea*), and coastal plain willow (*Salix caroliniana*). During the wet season from mid-May to November, the Everglades is hot (30–35 °C) and receives > 1 m of precipitation. From December to mid-May, the climate is cooler (12–25 °C) and dryer (≈ 40 cm rainfall; National Park Service 2024).

In the past few decades, there have been substantial changes to the Everglade's mammal and reptile communities. For example, many large nonnative reptiles have established active breeding populations; they include Burmese pythons, Green Iguanas (I*guana iguana*), and Argentine Black and White Tegus (*Salvator merianae*; Enge et al. 2004; Engeman et al. 2011; Krysko et al. 2016). Additionally, the southern portion of the Everglades has seen dramatic reductions in mesomammals, with once common marsh rabbits (*Sylvilagus palustris*) and raccoons (*Procyon lotor*) largely absent within the core python invasion range (Dorcas et al. 2012; Sovie et al. 2016; Taillie et al. 2021).

To test the efficacy of our lures, we selected three sites in the Greater Everglades that have relatively high python occurrences (Figure 1). Two of our sites, Frog Pond and Rocky Glades Public Small Game Hunting Areas (hereafter: Frog Pond and Rocky Glades), are adjacent to Everglades National Park, and have previously been used for research (McCampbell et al. 2023; Reed et al. 2011). Our third site, the C-4 Impoundment (hereafter:

C-4), is near the northern edge of Everglades National Park and also regularly records pythons (EDDMapS 2024).

Study design

We experimentally tested rabbit scent as a lure at 21 paired plots across our three study sites: eight at Rocky Glades, seven at Frog Pond, and six at C-4. We placed the paired plots 50 m apart and randomly assigned them as treatments or controls. We ensured that each pair was > 300 m separated from other pairs to help ensure spatial independence. Once weekly, we baited treatment plots with 500g of rabbit scent comprised of 80% feces, along with urine, and hair, that was collected from a local rabbit nursery. This amount of rabbit scent is approximately the quantity produced by two domestic rabbits in a week and is similar to that of native marsh rabbits (Forys and Humphrey 1997). We baited control plots with an equal amount of sterile soil. At each plot (n = 42), we deployed one game camera (Reconyx HP2X, WI, USA) within 2 m of the lure or sterile soil. We set the cameras to time-lapse, taking one photo per minute (Ryberg et al. 2021). We changed SD cards and camera batteries weekly and ran our experiment for 84 days from June 2022 to September 2022. We reviewed images using a hybrid method, employing an open-source object detection software (MegaDetector V5.0, Microsoft AI for Earth 2024, Beery et al. 2019) to remove images without animals and then manually reviewed the remaining images. We validated MegaDetector's effectiveness at detecting pythons and large (> 1 m) native snakes at a 0.05 confidence interval for our analysis before full implementation into our image review workflow (Miller et al. 2025). All camera trapping protocols were assessed and approved by the University of Florida's Institutional Animal Care and Use Committee (IACUC #201910726).

For each image, we identified snakes and mammals to the species level and flagged snakes without definable characteristics as unknown. We compared detection rates for pythons to determine if rabbit scent improved detection (see analysis, below). We also compared detection rates for non-python snakes because there is also a concomitant need for efficient and effective methods to detect native snakes and monitor their populations in the Everglades (Durso et al. 2011; McCampbell et al. 2024). Since rodents may be drawn to our lure (Otto et al. 2015) and pythons and native snakes regularly consume rodents (Casler et al. 2004; Romagosa et al. 2023), we recorded the number of rodent detections at each site to determine whether python and native snake aggregation was caused by increased prey availability.

Analysis

We considered each snake and rodent detection as independent if it was separated by at least an hour of the same species at each treatment or control for snakes and 15 minutes for rodents (Holinda et al. 2020; Neuharth et al.

2020). To assess differences in python, other snake, and rodent detections between treatments and controls we employed generalized linear mixed models using the glmmTMB package in the platform R (Brooks et al. 2017; R Core Team 2024) with independent detections as our response variable and treatment as our predictor variable. To isolate the effect of treatment, we calculated estimated marginal means (EMMeans) using the emmeans package (Lenth 2024). EMMeans allows us to estimate the average response variable at each level of a categorical variable, after accounting for fixed effects in the model (Searle et al. 1980). We included rodent counts for pythons and other snakes as predictors. We fit detection counts to a Poisson distribution and included paired treatments as random effects, to account for our paired study design. To prevent overfitting smaller datasets, we used Fisher's exact test if any category had < 5 detections. To determine if detection rates were best explained by the lure directly or increased rodent activity from the lure, we ranked models (rodent detections, treatment, and additive/interactive effects) based on their Akaike Information Criterion corrected for small sample size (AIC_c; Burnham and Anderson 2004). We considered models with < 2AIC_c units of the best model to be competing models. We report AIC_c, log-likelihood, and the number of parameters (K) for all models. We include the intercept in our K value.

Results

Our cameras recorded 4,795,193 images, of which 1546 contained snakes. We documented 11 independent python detections during image review (*n* treatment = 4, *n* control = 7). Further, we documented 662 non-python snake detections (*n* treatment = 360, *n* control = 302; Figure 2) of which we could identify 557 to the species level and 105 unknown snakes that we were unable to identify (Table 1). Using Fisher's exact test, we found no difference in python detections between treatment and control (Odds ratio = 0.60, 95% CI = 0.10–3.08, $P = 0.719$). However, rodents were more likely to be detected at treatment sites ($\beta = 0.441$, z-value = 7.702, $P \leq 0.001$). We estimated 2.95 (95% CI = 2.62–3.28) rodents at the controls and 3.39 (SE ± 0.168, 95% CI = 3.07–3.71) at the treatments. Evaluating the response of native snakes, we found rodent detections (AIC_c = 330.94) was the most parsimonious model with no other competing models (< 2 AIC_c, Table 2). Native snake detections were positively correlated with rodent detections, with the number of snakes detected increasing from five when one rodent was detected to 20 when over 100 rodents were detected ($\beta = 0.012$, z-value = 4.680, $P \leq 0.001$, Figure 3). However, there was no correlation between python and rodent detections ($\beta = 0$, z-value = −0.002, $P = 0.999$).

Discussion

Our experiment indicated that rabbit scent alone was insufficient to attract Burmese pythons. There was no difference in python detection between

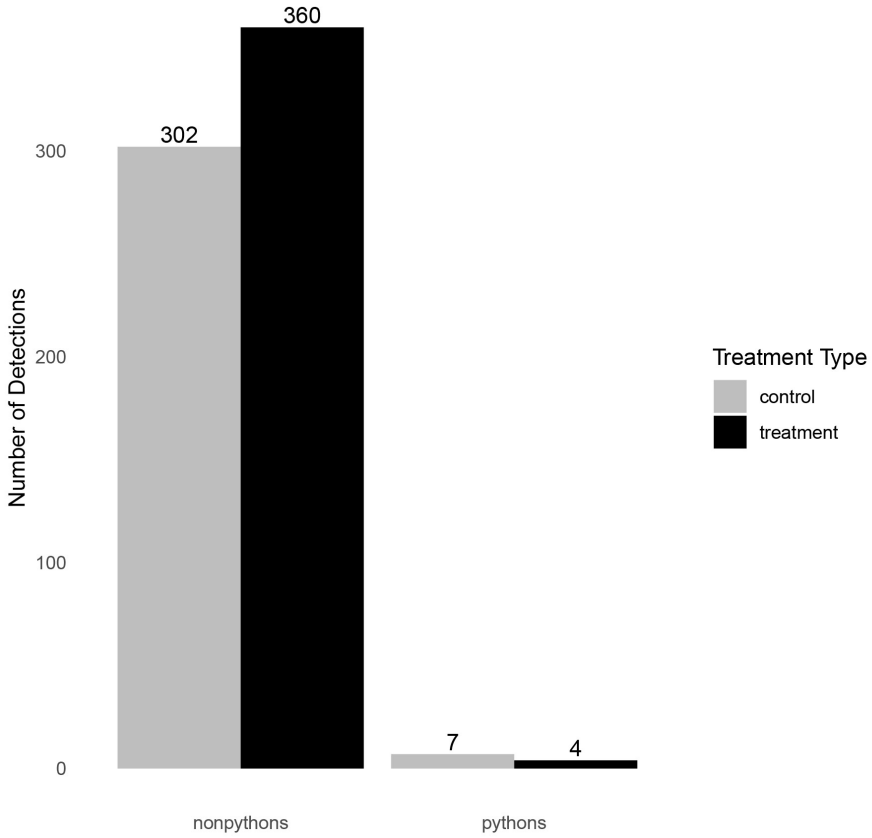

Figure 2. Cumulative totals of Burmese python and native snake independent detections between treatment types across all study sites in the Greater Everglades Ecosystem in south Florida, USA from June 21 – September 24, 2022.

Table 1. Classification of 673 snakes detected by cameras by treatment (control – sterile soil and treatment – rabbit scent) at C-4, Rocky Glades, and Frog Pond study sites in the Greater Everglades Ecosystem in south Florida, USA from June 21 – September 24 2022.

Scientific name	Common Name	C-4		Rocky Glades		Frog Pond		Total
		Control (n = 6)	Treatment (n = 6)	Control (n = 8)	Treatment (n = 8)	Control (n = 7)	Treatment (n = 7)	
Python bivittatus	Burmese Python	3	1	0	0	4	3	11
Coluber constrictor	North American Racer	57	74	18	16	180	143	488
Pantherophis guttatus	Eastern Cornsnake	0	3	5	1	2	8	19
Agkistrodon piscivorus	Cottonmouth	1	1	0	0	0	3	5
Thamnophis sirtalis	Gartersnake	3	18	0	0	0	0	21
Lampropeltis floridana	Florida Kingsnake	0	1	0	0	0	0	1
Pantherophis alleghaniensis	Eastern Ratsnake	1	5	0	0	6	3	15
Unknown	Unknown Snake	9	19	0	4	16	57	105
Thamnophis saurita	Eastern Ribbonsnake	1	3	0	0	1	1	6
Sistrurus miliarius barbour	Dusky Pygmy Rattlesnake	0	0	2	0	0	0	2
Total		75	125	25	21	209	218	673

Table 2. Model selection criteria for native snake detection ranked by their Akaike Information Criterion corrected for small sample size (AIC_c), and ΔAIC_c (difference between a model AIC_c and the top-ranked model), number of parameters (*K*), and log-likelihood values. Predictor variables include rodent (number of rodent detections), treatment (experimental treatment; scent lure or control), with additive and interactive effects. All models contain an intercept term.

Model Name	AIC_c	ΔAIC_c	*K*	Log-Likelihood
rodent	330.94	0	3	−162.15
rodent + treatment	333.10	2.16	4	−162.01
rodent × treatment	335.16	4.22	5	−161.75
treatment	346.74	15.80	3	−170.06

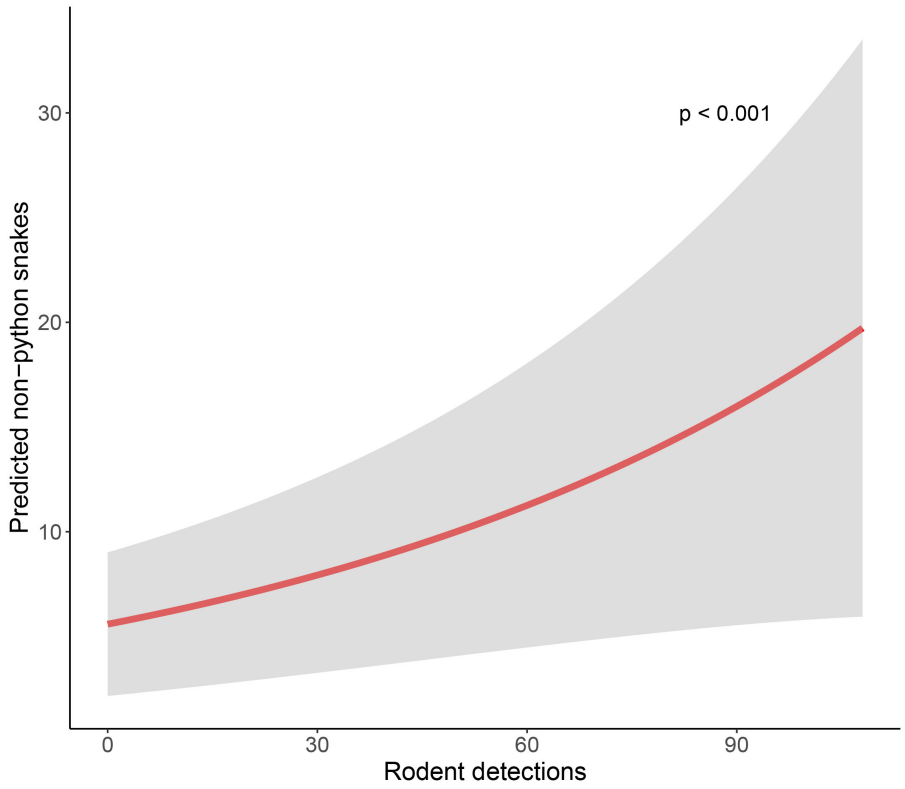

Figure 3. The predicted response of non-python snakes to rodent detections from a generalized linear model. The model was generated from rodent and non-python snakes detections at locations (n = 42) across the Greater Everglades Ecosystem in south Florida, USA. The trendline shows fitted values, and the shaded area represents 95% confidence intervals.

treatments and control, implying that pythons do not respond to prey scent alone. More native snakes were detected at treatment sites; however, this appears to have been best explained by increased rodent activity.

While live rabbits can attract pythons, we found no indication that scents alone can attract Burmese pythons and suggest that a multisensory lure may be more successful. For example, working on the invasive Brown Tree Snakes (*Boiga irregularis*), Shivik (1998) showed that combining both visual and olfactory cues outperformed individual cues alone. While adding a visual cue might increase the attractiveness of a scent lure for pythons, there is also support for the use of thermal cues. Emer et al. (2022) found that Burmese pythons can discriminate minute changes in temperature (as low as 0.5 °C) and showed reduced decision-making capacity when pit organs (thermal sensors) were physically occluded. Moreover, movement and vibration are important cues for snakes to find their prey (Haverly and Kardong 1996; Young and Morain 2002); thus, a prey replica that mimics these motions (Worthington-Hill et al. 2014) may also attract pythons. Future studies could explore the efficacy of combining additional cues with scents to enhance the attractiveness of lures for pythons.

Our mammalian lure increased the detection of rodents, possibly attracted to the nutritional value of the rabbit feces (Otto et al. 2015), which in turn increased the detection of native snakes, many of which prey

on rodents (Casler et al. 2004). Similarly, McCampbell et al. (2024) found that live rabbit lures increased the detectability of all snakes, including smaller species incapable of consuming rabbits. This suggests that live mammals and scent lures likely work through direct mechanisms (snakes attracted to rabbits) and indirect mechanisms (snakes attracted to species that are attracted to rabbit feces). These findings suggest that for many snakes, not just pythons, live mammals provide additional cues required to attract them, and that scent alone may be inadequate to reliably attract snakes. Further, while pythons prey on rodents and rabbits (Snow et al. 2007; Romagosa et al. 2023), using live rodents as python lures has had little success (Reed et al. 2011) compared to rabbits (McCampbell et al. 2024), suggesting the type of lure and strength of the cues likely play an important role in a successful python lure.

Burmese pythons remain difficult to detect in the Florida Everglades. While we found that a mammalian scent lure was ineffective at increasing detections, future research could test a multi-faceted lure that provides additional stimulus (e.g., thermal, visual, movement), thus bridging the gap between an effective living lure (McCampbell et al. 2024) and strictly scent-based lure. Camera traps have proven to be highly effective in detecting Burmese pythons, but the advancement of lure technology could help to improve detection rates, target high-risk areas, evaluate removal efforts, and support long-term management efforts.

Authors' contribution

SM: investigation, data collection, data analysis and interpretation, writing – original draft, review and editing. MK: funding provision, writing – review and editing. KH: funding provision, writing – review and editing. RM: research conceptualization, sample design and methodology, interpretation, ethics approval, writing – review and editing.

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Funding declaration

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Conflict of interest

None. Michael Kirkland is employed by the South Florida Water Management District. Kristen Hart is employed by the United States Geological Survey.

Ethics and permits

All camera trapping protocols were assessed and approved by the University of Florida Institution Animal Care and Use Committee (IACUC #201910726).

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