

Capsaicin-treated bait is ineffective in deterring non-target mammals from trap disturbance during invasive lizard control

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Abstract

Excluding non-target species from invasive species control efforts can be challenging due to non-target attraction to trap structure, baits, and lures. Various methods have been used to deter non-target species from entering or disturbing traps including altered features (e.g., mesh size, trip mechanism, or entrances), staking traps, and chemical deterrents. Invasive populations of Argentine Black and White Tegu lizards (*Salvator merianae*) occur in several locations across Florida and Georgia, and there are ongoing trapping efforts to control them. At sites in Georgia, non-target mammals disturb most of the lizard traps (>80%), consume egg bait/lures, and thus reduce trap efficacy. In contrast, our Florida site has fewer problems with non-target mammals. Our goal was to quantify the efficacy of capsaicin-coated eggs, a known distasteful irritant to mammals, as a non-target bait deterrent in live traps set for tegus in both Georgia and Florida. We conducted feeding assays on three tegus and found that individuals readily consumed food coated in capsaicin. We then conducted a three-part, live trapping experiment to test 1) if trap disturbance by mammals habituated to eggs without capsaicin decreased when capsaicin-coated eggs were deployed in Georgia, 2) if mammals not habituated to eggs as bait (treated or untreated) disturbed live traps at the same rate as those habituated to eggs in Georgia, and 3) if tegu capture rates were different when capsaicin treated eggs were deployed in Florida. In Georgia, we found that trap disturbance by non-target mammals did not decrease when capsaicin was applied to eggs in an area previously habituated to trapping with this bait nor when applied in a novel area. In Florida, we found no significant difference in tegu captures using capsaicin-treated vs. untreated bait. Tegus were tolerant of capsaicin, but capsaicin treated eggs did not reduce non-target mammal disturbance to traps. Therefore, removal of invasive populations could be problematic if methods to reduce trap disturbance by non-targets are not identified and deployed.

Keywords

deterrents, invasive species, live trap, non-target species, *Salvator merianae*, Tegu lizards

Introduction

Early detection and rapid response (EDRR; Westbrooks 2004; Reaser et al. 2020) to invasive species depends on effective sampling methodologies to detect, identify and/or capture target species (Morisette et al. 2020). Yet, any effects on non-target species must also be minimized. Traps are often used to remove invasives, however the specificity, efficiency, and cost of trapping efforts presents hurdles to invasive species management (e.g., Rodda et al. 1999). For EDRR efforts in particular, the consequences of not overcoming these trapping hurdles are potentially significant and can lead to a failure to eradicate the invasive population.

Excluding non-target species is challenging due to the variety of potential interactions species may have with traps. Non-target species may be attracted to traps as refugia or because a trap is placed in an area it forages (e.g., Peitz et al 2001). Likewise, non-target species may simply investigate, then trigger, the trap such that the target species will be excluded until the trap is reset. Whether a non-target species is captured (bycatch) or simply disturbs a trap, the result is a loss of trapping opportunity for target species. Lost trap opportunity thereby increases the time and cost of the trapping effort of the target species, making it harder and/or longer to achieve EDRR goals (e.g., delineate invasive species' population, eradication).

A variety of approaches have been used to deter nuisance species from an area or resource (Young et al. 2019; Werrell et al. 2021) and non-target species from traps (Peitz et al. 2001). Bycatch-reduction methods are common and include altered mesh size on traps or seines (Bohnsack, et al. 1989), or turtle excluder devices on trawling nets (Jenkins 2012). A variety of traps might be physically modified to alter the entrance so that greater specificity for the size and shape of the target species is achieved (Roden-Reynolds et al. 2018), or adjustment of the trip mechanism for a targeted species weight (or behavior) (Haro et al. 2020). Chemical attractants (Kimball et al. 2000; Landolt 2000) and deterrents (Kimball et al. 2009; Baylis et al. 2012; Burke et al. 2015; Lei and Booth 2017) have also been applied to nets, traps, or bait to increase trap specificity or to reduce the disturbance of traps by non-target species.

Increasingly, non-native reptile species are being introduced via human movement of goods or the pet trade (Lockwood et al. 2019; Orzechowski et al. 2019; Mazzamuto et al. 2021). Invasive Argentine Black and White Tegu lizards (hereafter, tegus; *Salvator merianae*) have been reported in 35 counties in Florida and at least four breeding populations have been established (Harvey et al. 2021). Tegus have broad habitat (Jarnevich et al. 2018), thermal (Currylow et al. 2021; Goetz et al. 2021), and dietary (Offner et al. 2021) requirements. Also, tegus have been documented eating threatened or endangered species such as hatchling gopher tortoises in

Florida (*Gopherus polyphemus*; Offner et al. 2021). In Georgia, numerous tegus have been trapped in two counties (Toombs, Tattnall; Haro et al. 2020), and in July 2019, a live-trapping program for tegus was initiated at the primary site of captures and reports in these two counties. Following protocols developed by the U.S. Geological Survey and the National Park Service for tegu trapping in Florida (described in Udell et al. 2022), live traps were baited with chicken eggs to capture tegus in Georgia. Almost immediately, tegu traps were disturbed by non-target species such that concerns arose that trapping efficiency was seriously reduced. Hence, solutions were sought to identify species that disturbed the traps, and to reduce trap disturbance.

Here, we document trap disturbance by non-target species and quantify the efficacy of using capsaicin-coated eggs as bait in live traps set for Argentine Black and White Tegus. Capsaicin is extracted from *Capsicum* plants and is both distasteful and an irritant to mammals (Osborn and Rasmussen 1995; Tewksbury and Nabhan 2001). Birds, however, tolerate capsaicin because they lack a functional receptor for it (Jordt and Julius 2002; Baylis et al. 2012). Given that birds are diapsid reptiles descendant from lizard-like theropods (i.e., extant birds and reptiles share a more-recent common ancestor than either group does with extant mammals), we suspect lizards may tolerate capsaicin. We conducted feeding assays on three tegus to quantify if tegus negatively responded to food coated in capsaicin. We then conducted a three-part, live trapping experiment to test 1) if trap disturbance by mammals habituated to eggs (bait) without capsaicin decreased when capsaicin-coated eggs were introduced, 2) if mammals not habituated to eggs as bait (treated or untreated) disturbed live traps at the same rate as those habituated to eggs, and 3) if tegu capture rates were different when capsaicin treated eggs were used.

Methods

Feeding trials

To evaluate if capsaicin-treated food items would deter tegus from feeding, feeding trials were recorded by presenting a tegu with odiferous, desirable food. Three subjects were fed between 28 May 2020 and 19 September 2020. Each subject was tested either 4 or 5 times, with two or more days separating feeding trials. Two tegus were long-term captive pets, and a third was wild caught but also a long-term captive animal. Each tegu was offered capsaicin-treated food item, then control food item, then capsaicin-treated food item again until the food ran out, or the lizards refused to eat any more food for more than two minutes. The order of treated / untreated food presented to each tegu was randomized at the start of each feeding trial.

Two lizards were fed raw chicken breast cut into approximately 6.45 cm² cubes. One lizard was also fed Vienna sausages (one can) because this was a highly desirable food item provided to it by its owner. Capsaicin-treated food was coated in

approximately 2 mL of a capsaicin solution. To make the solution, we dissolved 0.12 g of a commercial food additive (Mad Dog 357 Yellow Cake Capsicum Powder) per mL of distilled water. Mad Dog 357® Yellow Cake Capsicum Powder (hereafter “capsaicin powder”) advertises as 10% capsaicinoids by weight and 1,600,000 Scoville as determined through high-performance liquid chromatography. Control food items were moistened with tap H₂O. To facilitate data collection, each feeding trial was recorded on a smart phone with the lizard’s head in frame. Tongs were used to offer food items to the lizard.

Trapping

In May 2019, an incipient population of tegus was identified in south eastern Georgia, and live trapping began for their removal (Haro et al. 2020). The following year, live trap arrays were opened in Georgia on 17 March 2020 (site A, experiment 1), 18 March 2020 (site J, experiment 1), and on 26 April 2021 (site D, experiment 2; Fig. 1). Trap disturbance by non-target species rapidly increased thus we sought to evaluate non-target species response to capsaicin at sites with prior tegu trapping effort in 2019 (sites A and J) and sites without prior tegu trapping efforts (site D). Live trap arrays were opened in Florida (Miami-Dade) on 8 July 2021 (site F, experiment 3) to assess capsaicin treatment on tegu captures. Sites in Georgia used modified Havahart (Havahart, Inc., Lititz, PA, hereafter “live traps”) traps of small (L × W × H: 44.5 cm × 14.6 cm × 18.3 cm) and medium (L × W × H: 63.5 cm × 17.8 cm × 18.4 cm) sizes. Traps were modified by wrapping hardware cloth (0.64 cm mesh; dimensions L × W: 43.2 cm × 33 cm [small] and 63.5 cm × 48.3 cm [medium]) to prevent escape of juvenile tegus. When deployed, one door was kept closed to leave a single entrance. Traps were staked down by two 26-inch lengths of rebar positioned so they did not disturb the trap’s operation or tegu entry and were concealed as much as possible with leaf litter or sand. Traps at site A and D were deployed in a grid with 50 m spacing between traps. At site J, traps were placed 50 m apart in a linear array adjacent to an unpaved roadway. At site D, traps were spaced 100 m apart in four lines (5 traps per line), and lines were separated by 50 m. At site F, small live traps (similarly modified with hardware cloth) were deployed in a linear array along the verge and tree line of an unpaved roadway or within vegetation along canals and levees at 100 m spacing. Chicken eggs (capsaicin treated or not) were placed in hanging bait cages inside each live trap. Traps were checked daily and reset if needed. The egg was replaced if broken or missing or after 3 days if still present. Camera traps were aimed at baited live traps to document both tegus and non-target species (Moultrie Model # MCG-13331, MCG-13273) at sites A, J, and D. Doing so allowed us to monitor if traps were visited by tegus but were not catching them, and to identify non-target species that potentially decreased trapping efficiency. Camera trap data and batteries were exchanged weekly and photos analyzed within 1–3 weeks. To reduce the number of recaptures of the same individual in camera trap data, once a species was recorded near a trap in the frame, no additional individual of that species was recorded for 10 minutes following its first observation.

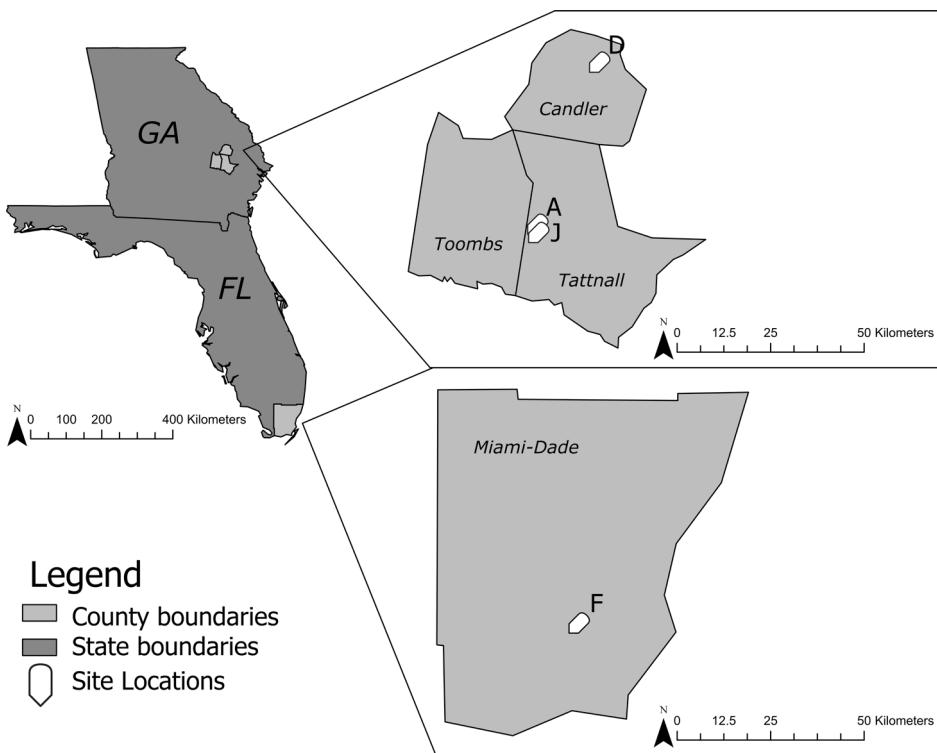


Figure 1. Map of study sites for experiments 1 and 2 in Georgia, and experiment 3 in Florida. Experiment 1 was carried out at site A and J (1.1 km from site A) in Tattnall County that contain habituated non-target species. Site A had numerous tegu captures and most of the trapping effort. Site J was a potential corridor for movement of tegus. Non-target species were habituated to both traps and chicken eggs as bait by the start of trapping on 17 March 2020. Experiment 2 was conducted at site D was in Candler County, 45.4 km north of site A. Site D did not have tegus nor were mammals habituated to traps with eggs as bait. Experiment 3 was carried out at site F near the eastern border of Everglades National Park in southern Florida (not shown), where tegu control efforts have taken place for approximately 10 years (see Udell et al. 2022).

Experiment 1: Trap disturbance with habituated non-target species (Georgia, sites A and J)

This experiment quantified trap disturbance rates and tested if non-target species habituated to traps baited with chicken eggs would be deterred by eggs treated with capsaicin. Trapping for tegus occurred at two adjacent sites: site A and site J, which were 1.1 km apart (Fig. 1). Trapping commenced at site J simultaneously because this site was a potential corridor away from site A and to a lowland stream corridor (Rocky Creek) that tegus may also use. We conducted experiment 1 at site A from 5 to 25 October 2020 in which control or capsaicin-treated eggs were used as bait. Site J continued to use untreated eggs during this period. Traps at both sites were closed for 4 days prior to re-opening on 5 October to begin the experiment. This experiment was conducted in October because tegu activity had ceased and thus the sampling was focused on mammalian responses to treated bait.

Treatment and control chicken eggs were lightly cracked by tapping with a hard object and a 16 ga needle was used to withdraw 10 mL albumin from each egg. Treatment eggs were injected with 10mL of a vegetable oil solution containing 0.55 g capsaicin powder per mL. Control eggs were injected with 10mL vegetable oil. Eggs were injected with treatment or control solution on the morning of deployment. Within the 33-trap array at site A, 17 traps received control eggs, and 16 traps received capsaicin treated eggs. Treatment designations were chosen using a random number generator to order traps. At the adjacent site J, 20 traps received untreated eggs (without treatment or control solution) as they had for the rest of the season. Eggs were replaced after being out for 72hrs (3 full days) if they had not been broken or eaten.

Experiment 2: Trap disturbance at novel site without habituated mammals (Georgia, site D)

This experiment tested if naïve mammals that were unexposed to live traps, eggs, or capsaicin-treated eggs would disturb traps as mammals did at site A. Site D was 45.4 km northeast from site A and site J. Opossums, raccoons, and similar mammalian mesopredators are present at site D (M. Cawthorn, C. R. Chandler, Georgia Southern University, verbal pers. comm. 2 April 2021). One trap array (20 traps) at site D received only untreated (control) eggs as bait, while an adjacent trap array (20 traps 70+ m south) was designated to receive only capsaicin treated eggs. A small wash ran through the middle of each site, and grid arrays were laid out the same, as they were in experiment 1. Traps were opened on 26 April 2021 and closed on 4 June 2021. Eggs in traps were replaced after being out for 72 hrs (3 full days) if they had not been broken or eaten.

In experiment 2, treatment eggs were prepared by brushing on 0.5 mL of a solution of 0.12g capsaicin powder per mL of distilled water. A disposable 1 mL pipette was used to drip the solution on the egg, then eggs were left in the refrigerator overnight to dry. We used this method because 1) it is less time consuming and easier to apply than injecting the eggs as in experiment 1, thereby providing a more feasible management option if effective, and 2) because mammals may be more easily exposed to capsaicin on the surface of the egg rather than inside the egg (i.e., detection does not require breaking the egg).

Experiment 3: Trap success on tegus using capsaicin treated eggs (Florida, site F)

As in experiments 1 and 2, we quantified if tegus were trapped at the same rate using either untreated or capsaicin-treated eggs as bait. Because tegus in Georgia are rarely trapped, this experiment was conducted in a larger, well-established population of tegus in southern Miami-Dade County, Florida, outside Everglades National Park (site F). Trapping efforts have been ongoing in southern Florida since 2012, and multiple organizations together remove hundreds of tegus each year (Harvey et al. 2021). Forty-one small live traps were deployed in a linear array at 100 m spacing in a crossover design. Every other trap was baited with a capsaicin-treated chicken egg ($n = 20$) or with chicken eggs ($n = 21$) from 8 July – 23 July 2021 (10 trap nights per trap). The treatments were reversed from 26 July –

13 August 2021 (12 trap nights per trap), and again from 16 August – 18 August 2021 (2 trap nights per trap). The cumulative trap night count was started over when control and treatment groups were switched. Consequently, each trap experienced each treatment for 12 full trap nights. The traps were opened every Monday, closed every Friday, and checked each intervening day. Baits were replaced each Monday or more often as needed.

Statistical analyses

To analyze the data, we calculated the proportion of disturbed traps for each day grouped by treatment (3 levels for experiment 1: control [site A], capsaicin-treated [site A], untreated [site J]; 2 levels for experiment 2: control [site D], capsaicin treated [site D]; 2 levels for experiment 3: control [site F], capsaicin-treated [site F]). For experiment 1, we additionally calculated the proportion of disturbed traps within each treatment by trap type (small modified, medium modified, or medium unmodified). For each day, a trap was counted as disturbed if there was any evidence of an animal physically interacting with the trap within a 24hr trapping period. Specifically, we counted a trap as disturbed if the trap had been falsely tripped (closed with no capture), if it had been flipped, if the bait was broken or missing, or if an animal was captured. We recorded a trap as undisturbed if the trap was found open and with bait intact after a 24hr period. To estimate trapping effort, we recorded an undisturbed 24hr trap night as 1, and a disturbed trap night as 0.5 under the assumption that a disturbed trap was fully available to capture an animal for an unknown proportion of the trapping period (we assume half the period as an estimate: Nelson and Clark 1973). We recorded a trap night for broken or missing traps as 0. We then calculated the cumulative trap nights for each day to be included as a covariate in each model. We did this to account for the effect of increased exposure to treatments on animal behavior (e.g., a raccoon may learn to avoid capsaicin treated traps over time).

We fit generalized-linear-models with a binomial distribution for each experiment using the built-in ‘glm’ function in R (version 4.1.1) software (R Core Team 2021). For experiment 1, we fit the daily proportion of disturbance predicted by treatment, trap type, cumulative trap night, an interaction between treatment and trap type, and an interaction between treatment and cumulative trap night. For experiment 2, we fit daily proportion of disturbance predicted by treatment, cumulative trap night, and an interaction between treatment and cumulative trap night. For experiment 3, we fit daily proportion of disturbance predicted by treatment, cumulative trap night, and an interaction between treatment and cumulative trap night. For experiment 3, we additionally fit the daily proportion of captured tegus predicted by treatment, cumulative trap night, and an interaction between treatment and cumulative trap night. We then tested for significance of explanatory variables using likelihood-ratio χ^2 tests using the ‘car’ package in R (version 3.1-2; Fox and Weisberg 2019). We considered effects significant if the probability of the observed χ^2_{DF} value was less than 0.05.

Data resources

Data analyzed in the study are available in McBrayer et al. 2023.

Results

Feeding trials

Each tegu fed freely in five trials where non-capsaicin-coated food items were presented ($\bar{x} = 12.8$ items ± 7.5 SD). During nine experimental feeding trials using capsaicin treated food, tegus ate both capsaicin and control food items (control: $\bar{x} = 5.78 \pm 4.84$ SD; capsaicin: $\bar{x} = 3.89 \pm 2.93$ SD). Both within and across trials, tegus ate capsaicin treated food and did not learn to refuse it. Yet, tegus ate more of the untreated food than capsaicin treated food (McBrayer et al. 2023).

Documentation of tegus and non-target species at the sites (A, J, and D) in Georgia

During the sampling period, eight tegus were observed on the cameras visiting traps. During our sampling period, at live traps without corresponding camera traps, two tegus were captured at site A.

Mammals comprised the majority of non-target observations in Georgia at sites A, J, and D (Table 1, Suppl. material 1: table S1), and the rate of trap disturbance varied spatially (i.e., among sites) and temporally (i.e., within sites as the experiment progressed). For context, one Opossum, one raccoon and two birds were documented in the first four days of camera trapping at site A, and trap visitation and disturbance by non-targets rapidly increased from this point forward (see below). Between 22 April 2020 to 03 October 2020, camera traps documented 1445 raccoons (*Procyon lotor*), 554 opossums (*Didelphis virginiana*), and 212 armadillos (*Dasyurus novemcinctus*) visiting or disturbing traps. In total, we gathered 3498 observations of 33 species (or taxa) via camera traps (Suppl. material 1: table S1). Most importantly, camera traps in 2020 documented that raccoons, in particular, disturb traps by trying to enter the trap, reaching inside (but not entering it), shaking and climbing on the trap, throwing it, etc. These actions caused the trip plate to trigger the closure of the trap door, whereby neither the mammal nor a tegu could be trapped. Although other taxa occasionally disturbed traps set for tegus (e.g., diurnal bird species, turtles, rodents; Haro et al. 2020 table 5), these taxa were frequently trapped, and thus easily identified, or were observed infrequently on game cameras.

Experiment I: Trap disturbance with habituated non-target species (Georgia sites A and J)

Before beginning experiment 1, trap disturbance rose quickly at sites A and J such that by mid-July 2020, resident mammals were habituated to traps baited with chicken eggs and it was not uncommon to have 100% of the traps disturbed each night. The focal site (site A) experienced a relatively high amount of trap disturbance (>0.8) immediately, while site J experienced lower daily disturbance until 1250 cumulative trap

Table 1. Summary of live tegu trap effort and success at four locations under three experiments (Exp.). In Georgia (GA), tegus were only captured at site A, while mammals were the principal taxon captured in live traps both at sites A, J, and D. Site J was 1.1km from site A (both in Tattnall County) and a potential movement corridor for tegus. Sites A and J contained non-target species habituated to live traps. Tegus were not present at site D (Candler County), and mammals at site D were not habituated to either live traps or bait (eggs). In Florida (Miami-Dade County), site F has high trapping success for tegus and lower rates of disturbance from mammals. Capsaicin treated bait failed to deter mammals or other taxa from disturbing eggs inside traps (McBrayer et al. 2023).

Site	Date Range	Treatment	Total Trap-nights	Total Animals Caught	Total Tegus Caught	Percent Mammals	Percent Non-mammals
A	Mar 17 – Oct 1, 2020	Untreated, Exp. 1	2746.0	26	2	73	27
J	Mar 18 – Sep 30, 2020	Untreated, Exp. 1	2103.5	32	0	59	41
A	Oct 5 – Oct 25, 2020	Capsaicin, Exp. 1	176.5	0	0	0	0
A	Oct 5 – Oct 25, 2020	Control, Exp. 1	192.0	3	0	100	0
J	Oct 5 – Oct 25, 2020	Untreated, Exp. 1	223.5	5	0	100	0
D	Apr 26 – Jun 4, 2021	Capsaicin, Exp. 2	511.5	4	0	100	0
D	Apr 26 – Jun 4, 2021	Control, Exp. 2	496.0	4	0	50	50
F	Jul 8 – Aug 18, 2021	Capsaicin, Exp. 3	419.0	40	31	17	83
F	Jul 8 – Aug 18, 2021	Control, Exp. 3	417.5	49	42	8	92

nights when disturbance rose to about 0.8 (Fig. 2A). Once trap disturbance rose to 0.80, it seldom abated for the remainder of the season (Fig. 2B). From May to August 2020, non-target species, principally consisting of raccoons and opossums, were verified with game cameras at site A.

Between 5 and 25 October 2020, traps at site A were baited with either capsaicin treated eggs, or control eggs. During this time, the proportion of disturbed traps did not change depending on trap type (GLM: $\chi^2_2 = 0.972$, $P = 0.615$), nor with cumulative trap nights (GLM: $\chi^2_1 = 0.026$, $P = 0.873$; Fig. 3). Traps using capsaicin treated eggs experienced the same level of disturbance as those treated with control or untreated eggs (GLM: $\chi^2_2 = 0.156$, $P = 0.925$). Thus, eggs treated with capsaicin did not result in lower trap disturbance by non-target species habituated to bait reward.

Experiment 2: Trap disturbance at novel site without habituated mammals (Georgia site D)

Non-target mammal species at site D became habituated to traps and eggs rapidly (see Suppl. material 1: table S2), just as they did at site A. Here, trap disturbance rose to > 0.80 in roughly 175 trap nights (Fig. 4). A significant relationship was found between cumulative traps nights and proportion of disturbed traps (GLM: $\chi^2_1 = 16.075$, $P < 0.001$). For a one unit increase in trap night, the odds of trap disturbance versus no disturbance increased by a factor of 1.008 (95% CI [1.004, 1.012]). This effect of cumulative trap night did not differ between treatments (GLM: $\chi^2_1 = 0.006$, $P = 0.936$). There was no significant effect of bait treatment on the proportion of disturbed traps (GLM: $\chi^2_1 = 0.439$, $P < 0.508$).

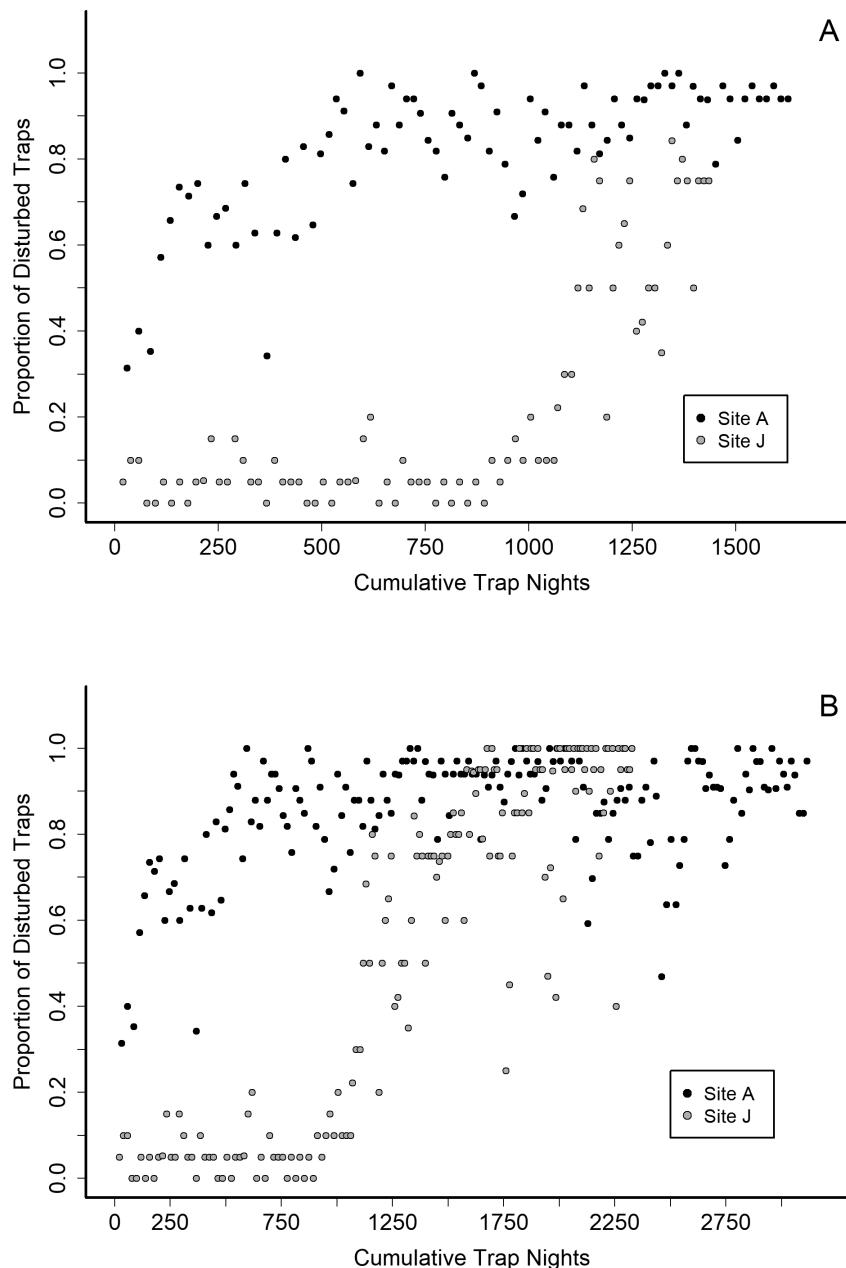


Figure 2. **A** proportion of traps disturbed early in the season (17 March to 15 June 2020) during experiment 1 at sites A and J in Georgia (McBrayer et al. 2023). Note that non-target species disturbed > 0.80 of traps within roughly 800 trap nights at site A, and 1250 trap nights at site J. **B** proportion of traps disturbed by non-target species across the entire season (17 March to 25 October 2020) in experiment 1 at sites A and J. Widespread trap disturbance continued for the remainder of the season. Black (site A) represents traps using control and capsaicin treated bait, while grey represents a site 1.1 km from site A (site J) that received only control eggs.

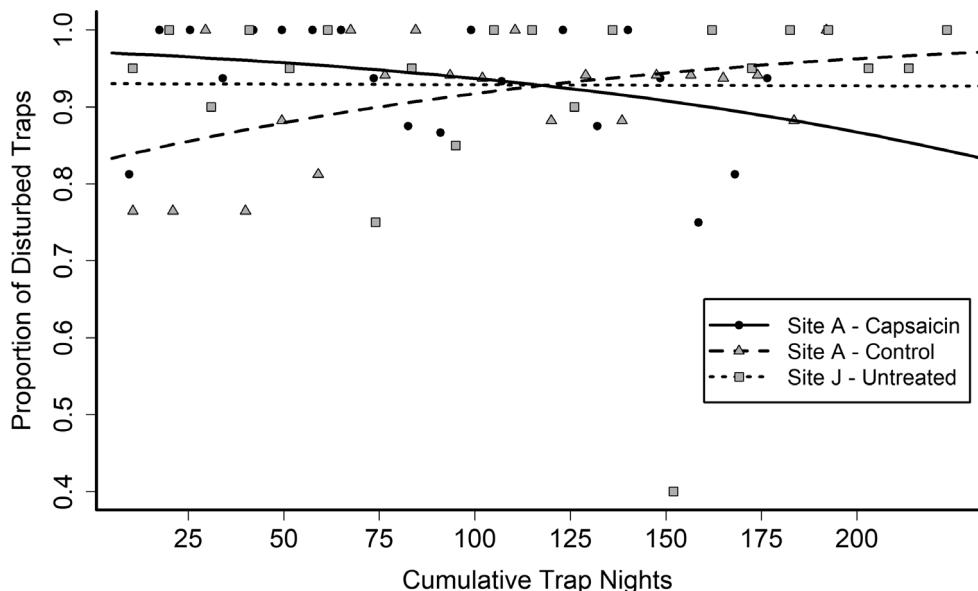


Figure 3. In experiment 1, the proportion of disturbed traps between 05 to 25 October 2020. Site A showed a decline by treatment type (capsaicin treated bait *vs.* control and untreated bait at two nearby sites A and J) over time in the direction expected, but the trend was not statistically significant. At each of the three sites, capsaicin did not significantly lower disturbance rates in this experiment (McBrayer et al. 2023).

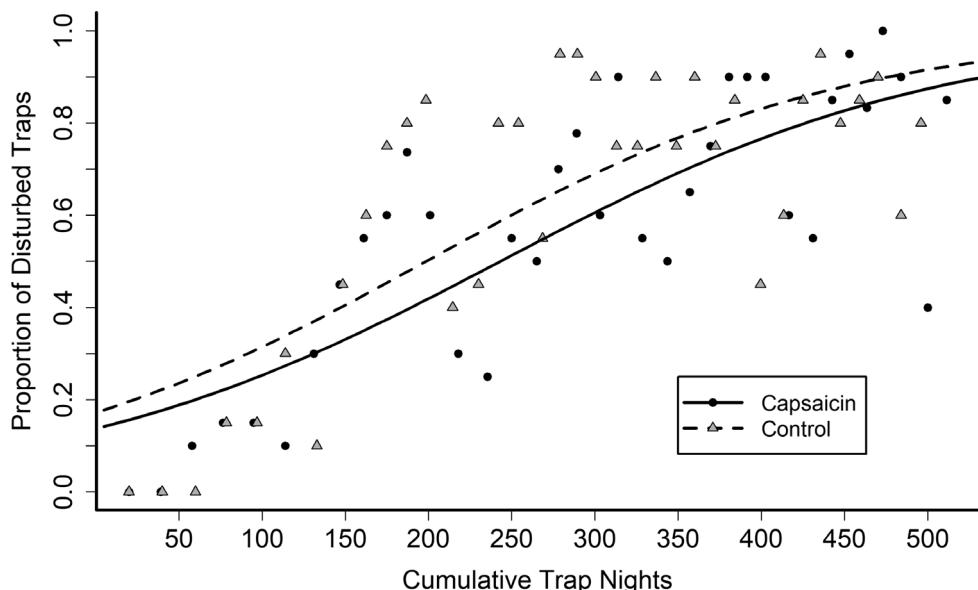


Figure 4. Trap disturbance in experiment 2 as a function of cumulative trap nights, where non-target species were not habituated to traps or bait (site D; 45.4 km from site A). Capsaicin-coated eggs did not significantly lower disturbance rates in this experiment (McBrayer et al. 2023).

Experiment 3: Trap success on tegus using capsaicin treated eggs (Florida site F)

In southern Florida (Miami-Dade, site F), 31 tegus were captured using capsaicin-treated eggs, whereas 42 tegus were captured using eggs without capsaicin; tegu capture rates did not significantly differ between bait type (GLM: $\chi^2_1 = 0.005$, $P = 0.941$). There was no effect of cumulative trap night on tegu capture rates (GLM: $\chi^2_1 = 0.012$, $P = 0.911$; Fig. 5). Though daily disturbance rates were relatively low at this site (mean = 0.25), there was not a significant difference in disturbance rates according to bait type (GLM: $\chi^2_1 = 0.002$, $P = 0.966$). Additionally, disturbance rates did not change as cumulative trap nights increased (GLM: $\chi^2_1 = 0.0002$, $P = 0.993$).

Discussion

Capsaicin-treated food did not deter three captive tegus from feeding in lab trials. Similarly, there was not a significant difference in tegu captures using capsaicin-treated vs. untreated baits at site F (Florida), though fewer tegus were trapped using capsaicin-treated baits. Together, these two experiments suggest tegus are likely tolerant of capsaicin. Although a promising finding, capsaicin-treated baits did not reduce the trap disturbance by non-target species at the sites in Georgia, where disturbance rates reach $\geq 80\%$ and are a significant impediment to trapping tegus. Non-target mammal species rapidly caused high trap-disturbance rates at site A where non-targets were likely habituated to traps baited with chicken eggs (experiment 1, Fig. 2). We suggest that non-targets became habituated to traps because (a) trapping occurred at this site in 2019 and disturbance was high, and (b) the rate of disturbance increased rapidly and was unchanged throughout the season, and (c) similar patterns were observed by non-targets without exposure to egg-baited traps or capsaicin (experiment 2, Fig. 4). Hence, rapid habituation to an egg reward may have contributed to the lack of any statistically significant effect of capsaicin to decrease trap disturbance.

Our results show how non-target disturbance varies spatially (within GA and GA to FL), which underscores how management strategies may also vary to effectively remove invasive species (Table 1). Daily disturbance rates in Florida (site F) are likely low for two reasons: one, the abundance of meso-mammals has significantly declined in association with invasive Burmese pythons and raccoons are now uncommon (Dorcas et al. 2012); and two, small, not medium, traps were used in Florida such that adult meso-mammals may be less likely to be trapped (if present). Adult tegus were trapped in medium traps in 2019 at site A (Haro et al. 2020). In 2020, small and medium traps were used to test if tegus would enter larger (medium) and/or smaller (small) traps. Raccoon and possum disturbed both trap sizes in Georgia, yet astonishingly few raccoons were actually trapped, instead simply disturbing the trap without getting captured. At site F, small rodents caused disturbance, but at low rates, possibly because they may be less interested in the bait and could be exploring traps as a novel aspect of the habitat. The somewhat trivial rate of trap disturbance in the Florida population does not warrant use of a deterrent since large numbers of tegus are caught annually.

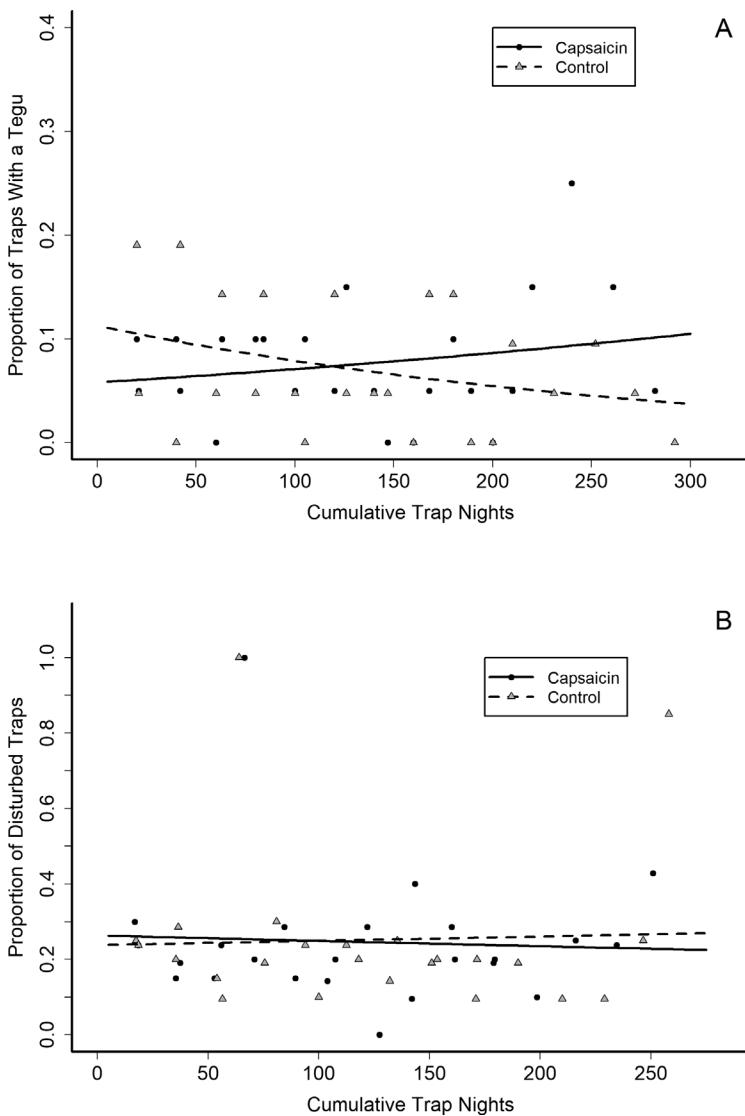


Figure 5. Tegu capture rates (**A**) and trap disturbance rates (**B**) during experiment 3 at site F. Neither tegu capture rates nor trap disturbance rates differed between bait treatment types in experiment 3. Non-target species did not disturb traps as much as at sites in southeast Georgia. Trap disturbance was not significantly associated with cumulative trap nights. Also, capsaicin treated bait did not have a significant effect on tegu capture rate (McBrayer et al. 2023). Trend lines added for visualization only.

(Harvey et al. 2021). Yet for the incipient tegu population in Georgia, trap disturbance is a more urgent issue because meso-mammals are abundant (Suppl. material 1: table S1), and EDRR efforts to remove tegus are compromised by trap disturbance.

Limited published data exist on reducing non-target trap captures. Standard suggestions include alternative capture methods or trap types, trapping timing (season

and time of day), bait, and trap placement (Peitz et al. 2001). Traps could be physically modified to specifically reduce the possibility of non-target disturbance. To that end, we staked our traps down with 0.4m long stakes of rebar at the Georgia sites, however doing so failed to decrease trap disturbance. Instead, future efforts might try covering the trap and its entrance with corrugated pipe (or similar) such that non-targets cannot reach into the live trap (Roden-Reynolds et al. 2018).

Another approach to mitigate non-target species disturbance could be to open traps based on target vs. non-target species behavior or activity time. Raccoons are known to move between major and minor feeding areas during the night (Lotze and Anderson 1979). Understanding non-target species movements could help place traps in non-foraging areas or areas with less movement by non-target species. Camera traps revealed low rates of diurnal species entering or disturbing traps (raccoons and birds were most common), yet reptiles and amphibians were rare (Suppl. material 1: table S1; McBrayer et al. 2023). For smaller trap arrays for diurnal target species, closing traps or removing bait from traps near sunset, and replacing bait again near sunrise, may present a feasible method to reduce trap disturbance by nocturnal species. Yet, removing bait or closing traps at night would be labor intensive and costly. At site F (Florida), the use of capsaicin-treated bait increased the time to set or reset traps which also increased the time to run trap lines. An effective deterrent for non-target species would be widely available and inexpensive, simple to introduce and quickly implement, and be highly deterrent if it is to be adopted on a large scale (e.g., Lacey et al. 2015).

Chemical (gustatory) and olfactory deterrents may continue to show promise (e.g., Conover, 1989), even though capsaicin was not effective here. Coyote urine is not an effective deterrent for raccoons or opossums (Yocom-Russel and Verble 2020). However, 2% anthraquinone was shown to repel raccoon feeding on corn by 71%. Anthraquinone is a naturally occurring compound and has been used to repel rodents, rabbits (Werner et al. 2016), and pigs (Snow et al. 2021), though it also repels birds (DeLiberto and Werner 2016), suggesting it may have a similar repellent effect on tegus and other reptiles. Likewise, conditioned food aversions may have the potential to deter some species (reviewed in Snijders et al. 2021). In a captive trial, raccoons developed a taste aversion to oral estrogen concealed in an egg (Dueser et al. 2018). Hence, conditioned food aversion trials to deter problematic species like raccoons could be conducted prior to invasive species trapping.

Conclusion

Tegus represent a threat to native species once established (Klug et al. 2015; Mazzotti et al. 2015; Haro et al. 2020). Thus, future experiments to understand how non-target species might be efficiently deterred from disturbing live traps for this invasive species may be useful for control. Here we show that raccoons and opossums readily learn to disturb live traps set for tegus and are not deterred by bait coated with capsaicin. Removal of incipient populations of tegus could be fraught with difficulty if methods to reduce trap disturbance are not identified and deployed.

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Supplementary material I

Species lists of non-target species disturbing traps set for tegu lizards

Authors: Lance D. McBrayer, Daniel Haro, Michael Brennan, Bryan G. Falk, Amy A. Yackel Adams

Data type: Occurrence data

Explanation note: Species observed at one site during the study and species observed at a second sites about 40 km away.

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