Confirming the utility of camera traps in field studies of predation

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Artificial prey techniques—wherein synthetic replicas of real organisms are placed in natural habitats to study predator-prey interactions—have become a standard method for studying predation in the field. Although widely used by ecologists and evolutionary biologists, artificial prey techniques have a few major shortcomings, most notably they provide no insight into interactions between predators and unmarked prey. Camera trapping technology has been increasingly used to monitor predator activity near artificial prey to ameliorate some of the shortcomings of artificial prey techniques. However, most studies employing cameras have used still images, which has a limited capacity to document interactions between predators and artificial prey. Here, we confirm the utility of videography for enhancing results obtained from artificial prey experiments. We conducted three artificial prey experiments at three separate locations in the Americas and employed camera traps that took videos at a subset of sites. Videos revealed that the frequency at which predators detected but did not attack replicas was higher than the frequency at which replicas were attacked. In addition, mammalian predators were more commonly detected than avian predators. Overall, our results demonstrate that videography could be used to substantially improve the study of predation in the field.

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Keywords artificial prey, camera trap, clay model, field experiment, predation, videography

Abstract

Artificial prey techniques—wherein synthetic replicas of real organisms are placed in natural habitats to study predator-prey interactions—have become a standard method for studying predation in the field. Although widely used by ecologists and evolutionary biologists, artificial prey techniques have a few major shortcomings, most notably they provide no insight into interactions between predators and unmarked prey. Camera trapping technology has been increasingly used to monitor predator activity near artificial prey to ameliorate some of the shortcomings of artificial prey techniques. However, most studies employing cameras have used still images, which has a limited capacity to document interactions between predators and artificial prey. Here, we confirm the utility of videography for enhancing results obtained from artificial prey experiments. We conducted three artificial prey experiments at three separate locations in the Americas and employed camera traps that took videos at a subset of sites. Videos revealed that the frequency at which predators detected but did not attack replicas was higher than the frequency at which replicas were attacked. In addition, mammalian predators were more commonly detected than avian predators. Overall, our results demonstrate that videography could be used to substantially improve the study of predation in the field.

Introduction

The study of species interactions is central to evolutionary ecology (Pianka, 2000). Studies of predator-prey interactions are often difficult since natural predation events are challenging to observe (Irschick and Reznick, 2009). Moreover, the ability of the rare observation of single predation events to provide general insights into predator-prey interactions is inherently limited. Artificial replicas of prey species are commonly used to study predation in the wild. Such facsimiles allow key features of prey phenotypes (e.g., color, pattern, shape, or size) to be easily manipulated and produced in large numbers, thereby allowing predation to be studied in diverse natural populations (Irschick and Reznick, 2009). Replicas have been used to address a wide variety of evolutionary and ecological questions, ranging from predator psychology to aposematism and mimicry (reviewed in Bateman et al., 2017).

Replicas of naturally occurring prey have been used to measure predator-mediated natural selection in diverse taxa, including insects (Lövei and Ferrante, 2017), fish (Caley and Schluter, 2003), frogs (Saporito et al., 2007), salamanders (Kuchta, 2005), turtles (Marchand et al., 2002), lizards (Stuart-Fox et al., 2003), snakes (Pfennig et al., 2001), birds (Ibáñez-Alamo et al., 2015), and mice (Vignieri et al., 2010). Generally, these studies involve constructing replicas (e.g., of pre-colored, nontoxic clay) bearing different colors, patterns, and shapes and placing several hundred of these in natural habitats, where they are exposed to predation by naturally occurring, free-ranging predators. After a pre-determined period of time, each replica is scored as attacked or not based on the number and type of marks left on it. Conclusions are then made based on the patterns of attacks across phenotypes and/or habitats.

This traditional approach of using replicas to study predation in the field has three major shortcomings (Irschick and Reznick, 2009). First, predation attempts—and the identity of the predators—are inferred (Irschick and Reznick, 2009). In most cases, distinguishing marks left by predators from non-predatory disturbances (e.g., footprints) is straightforward (e.g., Brodie, 1993). It is also often possible to broadly classify the type of predator based on the type of markings left on the replica (e.g., beak imprints indicate avian predation). However, some marks can be ambiguous, which might make it difficult or impossible to classify predator type (Irschick and Reznick, 2009). Second, only a subset of interactions between replicas and predators can be "seen" from marks left on replicas (Irschick and Reznick, 2009). For example, predators might detect the replicas and decide not to attack them (Willink et al., 2014). Noting the frequency of this behavior might prove especially useful to studies of aposematic and mimetic taxa because aposematic phenotypes are expected to foster the evolution of avoidance behaviors in predators (Smith, 1975; Smith, 1977). Moreover, most studies consider "unattacked" replicas to be equivalent; however, the ability to distinguish between replicas that were detected and not attacked and replicas that were never detected would allow for more power in statistical analyses. Third, replicas are unlikely to sample all potential predators (Irschick and Reznick, 2009). Predators that rely heavily on movement (e.g., felids) or smell (e.g., canids) to detect prey might ignore motionless or odorless replicas (Irschick and Reznick, 2009). The quality of field-based studies using artificial prey techniques would be greatly enhanced if the identity and abundance of predator species could be reliably determined.

Camera trapping technology provides a potential solution to these shortcomings. A camera trap consists of a remotely activated camera that is equipped with a motion or an infrared sensor (some also use a light beam as a trigger). When placed in the field, such a setup provides a method for capturing still images or video of wild animals when researchers are not present. This technology has been used in ecological research for decades (Savidge and Seibert, 1988;

Griffiths and van Schalk, 1993; O'Connell et al., 2011; Burton et al., 2015), typically to detect or survey the abundance of naturally occurring animals. Camera traps also offer a minimally invasive way to identify predators and directly observe predator behavior (but see Meek et al., 2014; Meek et al., 2016). Although several field studies of predation have experimented with camera trapping techniques, most of these studies have used still images to monitor predator activity near artificial prey (Caravaggi et al., 2017). While photographic monitoring does enhance predator identification (e.g., Francis et al., 2009), photographs are often insufficient for determining whether predators attacked—or detected but did not attack—artificial prey (e.g., Cotterill and Hannon, 1999; Purcell and Verner, 1999; Fies and Puckett, 2000). Videography provides a superior alternative for characterizing interactions between predators and artificial prey that are incapable of being inferred from marks left on replicas.

Here, we present the results of three independent field studies that each employed hundreds of clay replicas and camera traps to confirm the ability of videos to enhance results obtained field studies of artificial prey. We collected data on all of the potential predators captured from cameras placed in each field experiment. We used camera trap videos to score attacks on clay replicas and compared these scores to attack scores made in the field before camera trap footage was reviewed. We also used camera trap videos to quantify the frequency at which predators detected but did not attack replicas. We conclude by discussing some of the costs and benefits of using camera trapping techniques in field studies of predation.

Materials and Methods

Ethics Statement

Data collection used non-invasive, remotely-triggered camera traps and hence did not involve direct contact or interaction with animals. The clay used in all experiments is nontoxic. Fieldwork was done under the following permits: Ecuador - N° 002-017 IC-FAU-DNB/MA; Mexico - SGPAJDGVS/09347/16.

Camera Trap Experiments

Three field experiments using clay replicas of coral snakes and coral snake mimics were placed at three separate locations in the Americas to assess the ability of camera traps to enhance field studies of predation (Fig. 1). The first experiment was conducted in February of 2017 in Amazonian lowland rainforest at Tiputini Biodiversity Station, Orellana, Ecuador (~0°37'S, 76°10'W, 190-270 m asl; Table 1). The second experiment was conducted from June to July of 2017 in Lacandon premontane wet rainforest at Nahá Reserve, Municipality of Ocosingo, Chiapas, México (~16°58'N, 91°35'W, 800-1200 m asl; Table 1). The third experiment was conducted from October to November of 2017 in longleaf pine forests of the Sandhills and Coastal Plain of North Carolina, USA (~34°45'N, 78°32'W, 0-150 m asl; Table 1). Clay replicas in all experiments were constructed using pre-colored, odorless, nontoxic Sculpey III modeling clay. Measurements of preserved snake specimens from several museums (AMNH, FLMNH, FMNH, MPM, NCSM, UIMNH, USNM, UTA) and pictures of live specimens were used to design prey phenotypes in each experiment.

Because each field experiment was a part of its own independent study, the experiments varied in several ways (Table 1). We used several relatively inexpensive (<$100 each) digital camera traps (Spypoint Force 10, Scout Guard SG560V-31B, ANNKE C303, Bestguarder DTC-880V) triggered by an infrared motion-and-heat detector to document activity near replicas. All cameras used a variable number of AA batteries and were equipped with 32-gigabyte SD cards.

In all experiments, we attached cameras to the trunks of trees and positioned them ~0.75–1 m above the surface of the ground at an approximately 45-degree downward angle. Although vegetation that might falsely trigger the cameras was cleared prior to arming the cameras, we tended to place cameras in sites that were devoid of such vegetation to minimize disturbance to the habitat. All cameras were programmed to take 60-second videos when triggered (except when batteries failed or other malfunctions occurred). All videos were associated with data on the location (from GPS), identity of the camera, date, time, and species (from video files).

All vertebrate species that triggered the cameras were recorded. We classified videos as belonging to independent records if more than 30 minutes had elapsed between consecutive videos of the same species at the same location. We used 30 minutes as a cut-off because visits by herds of peccaries (*Tayassu pecari* and *Peccari tajacu*) were typically the longest of any species at any given site among the three experimental locations, but most visits were less than 30 minutes. Vertebrate species were classified as potential predators if the species could represent a threat to an average-sized coral snake (ca. 500 mm). Although this classification scheme might seem excessively loose, several species that have not been documented to consume snakes are still perfectly capable of fatally injuring a snake and thus contributing to predator-mediated natural selection. Birds (e.g., passerine, dove, and tinamou species) and mammals (e.g., small rodent and lagomorph species) not considered to be predators would not represent threats to real snakes (S1 Table). When discernable, markings left on replicas from such predators were not scored as attacked in the field.

The behavior of predators was noted if the predators clearly detected the replica (i.e., the predator decreased the rapidity of its movement near the replica and directed attention toward the replica either with its eyes or nose). Predators were scored as having attacked a replica if the predator bit a replica. Predators were scored as having "avoided" a replica if the predator clearly detected the replica and decided not to bite it. Obviously, it is difficult to distinguish between whether a predator failed to recognize a replica as a snake or whether a predator genuinely recognized a replica as a snake and decided not to bite it. Thus, when we use avoid, we do not imply the latter; instead, we use avoid to refer generally to either scenario. In the field, replicas were scored as attacked, not attacked, or missing (i.e., there was no trace of the replica) based on the presence or absence of tooth and beak marks prior to reviewing footage from the cameras. We then assessed the match between scores made in the field and scores made using camera trap footage. Using the camera trap data collected from all of the cameras from each experiment, we tallied the number of predator-replica interactions, attacks, and avoidances.

Results

A total of 14 (Ecuador), 7 (Mexico), and 31 (North Carolina) videos were available for analysis (i.e., videos that captured predators interacting with replicas; Table 2; see Fig. 2 for examples). Across all three experiments, predators were more often observed to avoid replicas rather than attack replicas (37 avoidances vs. 18 attacks). Animal visitation rate (number of detections/# of trap-days at each study location) near the replicas varied between study location (Table 2). The rate of attack and avoidance behaviors (number of attacks or avoidances/# of trap-days at each study location) also varied among study location (Table 2). Mammalian predators were more commonly detected from our cameras than avian predators at all experimental sites (Table 2). Diversity of predator species captured on cameras was highest in Mexico (10), followed by Ecuador (8), and North Carolina (6) (Table 3).

Ecuador

Four cameras failed to capture any usable footage throughout the course of the experiment. A total of 55 detections of predators were made from the rest of the cameras. Although birds attacked replicas more frequently than mammals (22 mammalian attacks vs. 33 avian attacks) based on markings left on clay, mammals were more commonly detected near replicas than birds (Table 2). Of these 55 detections, there were 14 separate interactions between predators and replicas: 2 attacks and 12 avoidances (Table 2). Predator-replica interactions were dominated by collared peccaries (*Pecari tajacu*) (9/14), followed by gray-winged trumpeters (*Psophia creptians*) (4/14) and white-lipped peccaries (*Tayassu pecari*) (1/14).

The two attacks that were scored from the cameras did not match clay-based scores. The first attack observed from camera footage was by a group of *T. pecari* at 1511 h that bit and removed a replica from the initial site that it was placed (S1 Video). This replica was scored as missing in the field since this replica was not located near the original position it was placed. This replica was later found approximately 4 m away from the site where it was originally placed after inspecting the footage from the camera. The second attack observed from camera footage was by a pair of *P. crepitans* that repeatedly bit a replica at 0841 h (S2 Video). Impressions left on this replica were difficult to diagnose as bird predation in the field; thus, the replica was scored conservatively as not attacked in the field. All avoidances took place during daylight hours.

Mexico

All cameras captured usable footage throughout the experiment except for one camera. A total of 54 detections of predators were made from the rest of the cameras. Attacks by mammalian predators were slightly more common than attacks by avian predators as determined from clay markings (92 mammalian attacks vs. 78 avian attacks); however, mammalian predators were more commonly detected on cameras than avian predators (Table 2). Of these 54 detections, there were 7 separate interactions between predators and replicas: 6 attacks and 1 avoidance (Table 2). Interactions were dominated by gray foxes (*Urocyon cinereoargenteus*) (5/7), followed by common opossums (*Didelphis marsupialis*), (1/7), and nine-banded armadillos (*Dasypus novemcinctus*) (1/7).

The six attacks that were scored from the cameras did not completely match clay-based scores. Three of the *U. cinereoargenteus* that attacked replicas were observed on cameras to remove replicas from their original location without leaving a trace of clay (e.g., S3 Video). Thus, these replicas were scored as missing in the field, as they could not be located by the observers. At another site, a *U. cinereoargenteus* bit a replica and left the site, leaving the replica in place. This replica was not present at the site when it was later checked and was thus scored as missing in the field. Oddly, this replica was also not present in the next video that the camera took (taken 3 days later). Thus, the fate of this replica is uncertain. At another site, a *D. marsupialis* quickly and lightly bit a replica (S4 Video). This one bite mark was too superficial to score as an attack in the field. The only attack score that was clearly observed on cameras and also inferred in the field was an attack by a *U. cinereoargenteus* that ate most of the clay of a replica (S5 Video). All attacks took place during the day except for the attack by *D. marsupialis* which occurred at 0029 h. The one avoidance by *D. novemcinctus* took place at 0234 h.

North Carolina, USA

Five cameras failed to capture any usable footage throughout the course of the experiment. A total of 148 detections of predators were made from the rest of the cameras. Markings left on clay indicated that mammalian predators attacked far more replicas than avian predators (196 mammalian attacks vs. 16 avian attacks). Mammalian predators were also more commonly detected than avian predators (Table 2). Of these 148 detections, there were 31 separate interactions between predators and replicas: 10 attacks and 21 avoidances (Table 2). Interactions were dominated by common raccoons (*Procyon lotor*) (17/31), followed by *U. americanus* (6/31) *U. cinereoargenteus* (5/31) and Virginia opossums (*Didelphis virginiana*) (3/31).

The 10 attacks that were scored from the cameras matched scores made in the field. Four of the attacks were by *U. americanus* (e.g., S6 Video), three of the attacks were by *P. lotor* (e.g., S7 Video), two of the attacks were by *U. cinereoargenteus*, and one attack was by a *D. virginiana*. Seven replicas that were in front of cameras throughout the experiment were scored as attacked in the field (due to the presence of tooth marks), but there was no footage taken of predators attacking these seven replicas nor was there any footage suggesting which animals might have been responsible for producing such impressions. All attacks took place at night except for two attacks by *U. cinereoargenteus*: one right before sunset at 1803 h and one in the morning at 1009 h. All avoidances took place at night except for one at 1751 h right before sunset by *U. cinereoargenteus*.

Discussion

Our series of experiments confirms that the use of videography can enhance field studies of predation employing artificial prey techniques. Videography allowed predators that attacked replicas to be conclusively identified. Camera footage also permitted four missing replicas to be correctly scored as attacks and two replicas that were scored as not attacked in the field to be correctly scored as attacked. Given that only 0.02% (Ecuador), 0.015% (Mexico), and 0.09% (North Carolina) of replicas in each experiment were placed in front of functional cameras, placing cameras in front of a higher proportion of replicas would certainly augment the quality of data that could be obtained from such field experiments. If cameras were employed at the scale of each entire experiment in our study and assuming that predation occurred at the rate observed among the set of cameras employed in each experiment, approximately 100 (Ecuador), 400 (Mexico), and 111 (North Carolina) attacks would have been expected to be recorded.

In addition, videography permitted the documentation of behaviors that could not be inferred from bite marks; specifically, cameras captured 37 instances in which predators detected—but did not attack—replicas. If cameras were employed at the scale of each entire experiment, approximately 750 (Ecuador), 66 (Mexico), and 344 (North Carolina) avoidances would have been expected to be recorded. Such data on the frequency at which predators avoid artificial prey can have important implications for interpreting the results of artificial prey experiments. For example, replicas that are scored as “unattacked” are often lumped into a single category for analysis in most studies, but replicas that are detected and not attacked and replicas that were never detected by a predator should not be considered equivalent in statistical analyses. Thus, data collected from camera traps on the frequency at which predators detect replicas could be used to increase the statistical power of analyses if analyses were restricted to replicas that were actually detected by predators.

Although the relative abundances of mammalian and avian predators at each experimental locality is unknown, the use of remote videography in our study suggests that artificial prey techniques might sample a biased subset of the predator community. Detections of mammalian predators were much more common than detections of avian predators across all study locations (Table 2; Table 3). This bias might not be trivial given that avian predators might make a larger contribution to shaping the adaptive landscape of color pattern phenotypes relative to mammalian predators—especially in the tropics (Brodie, 1993; Hinman et al., 1997). One possible explanation for the higher frequency of mammalian predators is that mammalian predators used the human scent left behind at each site during camera trap setup to locate the replicas, whereas birds, being less olfactory-driven, would not have used olfactory cues to locate replicas. We consider this explanation unlikely given that there was no evidence from several of our cameras located in close proximity that predators were following a human scent trail.

Videos from cameras also suggested that predator species that might rely heavily on movement to detect prey (e.g., *Leopardus pardalis*) failed to react to replicas in their direct path. Incorporating movement into clay replicas increases attack rates (Paluh et al., 2014); however, simulating movement in replicas of certain taxa (e.g., snakes) at the scale of an entire experiment poses a considerable logistical challenge. Nevertheless, efforts to increase the realism of replicas should be explored because more realistic replicas would increase the proportion of the predator community that could be sampled, potentially negating the need to employ extremely high numbers of clay replicas—and camera traps—to detect effects between phenotypes (e.g., Paluh et al., 2014). At the very least, videography provides a tool for identifying predators that may encounter prey species more frequently and thus might be important agents of selection for their anti-predator traits.

Although this study demonstrated that camera trapping techniques provide substantial benefits to field studies of predation, these benefits do not come without costs. The costs of good quality camera traps can be substantial. The cameras used in our experiments were among the least expensive models available in the U.S. (<$100 each). If cameras were employed at the scale of each entire experiment in our study and the cost per camera is $100 (and assuming that all experimental trials were not staggered temporally), the total cost of cameras to conduct each experiment would be prohibitive (Ecuador - $135,000; Mexico - $105,000; North Carolina, USA - $20,000). The total costs of 32-gigabyte SD Cards and AA batteries for all cameras (assuming each camera required one 32-gigabyte SD Card and six AA batteries) would also be substantial (Ecuador - $18,700; Mexico - $14,600; North Carolina, USA - $2,800). Although the costs of camera traps are decreasing, there are methodological modifications that would permit these costs to be reduced (e.g., by staggering the use of cameras temporally so that fewer artificial prey would need to be monitored at any one time). Nevertheless, one question that follows from our study is whether the potential costs of camera traps are justified given the data that are made available. Other methods (e.g., DNA-based methods for identifying predators) might offer cheaper, less demanding alternatives and provide similar information. However, the principal benefit provided by camera traps is that they provide data on predator presence, abundance, and behavior. Other methods (e.g., DNA samples, tracking stations, etc.) provide comparatively limited information.

Other costs also deserve consideration by researchers. The risk of cameras failing for unknown reasons might vary with the model of camera. There were cameras in each experiment that failed to function even though all of the recommendations from the manufacturers were followed. In addition, several cameras apparently failed to capture footage of predation events as several replicas that were in front of cameras were undoubtedly attacked in the field. The use of camera traps also poses considerable logistical costs. Installation of camera traps approximately tripled the amount of time it took to set up each replica or set of replicas. Field assistants substantially enhance the efficiency of camera trap setup and takedown and would be essential for employing camera traps at a larger experimental scale. Transportation of the cameras to field sites (e.g., by airplane) can also incur additional substantial costs.

Future field studies of predation using artificial prey techniques should also consider the arrangement of replicas within transects and the structural features of the habitat when employing cameras. Replicas in Ecuador and Mexico were placed singly (one camera per replica), whereas replicas in North Carolina were placed in triads (one camera per three replicas). In North Carolina, cameras needed to be placed further from the replicas in order to ensure that all of the replicas in a triad were in the field of view. However, increasing the field of view both increases the likelihood that small animals interacting with replicas will fail to trigger the cameras and the frequency at which blowing vegetation will trigger cameras. This trade-off between detecting predators and minimizing false positives is illustrated by our unsuccessful attempt to conduct the North Carolina field experiment using camera traps in the spring of 2017. During this experiment, we set all cameras to their highest sensitivity setting to ensure that small animals interacting with replicas would not be missed by the cameras. However, a few windy days late in the experimental period during the spring experiment caused the majority of the SD cards in these cameras to be filled with videos of blowing oak leaves and wiregrass, which resulted in the loss of all of the previous footage that was taken during the first two to three weeks of the experiment. We therefore set all cameras to a medium sensitivity setting for the fall experiment in North Carolina. This setting change greatly reduced false positives, but this reduction in sensitivity might explain why there were seven replicas that were clearly attacked in the field that were not captured on the cameras.

Given the increasing use of artificial prey techniques and camera traps, there is also a need for standardization in future field studies of predation to facilitate data management, reporting and sharing. Inconsistencies in data reporting and data storage among field studies using artificial prey will greatly impede data aggregation and data sharing in the future. While it is beyond the scope of this paper to propose a data standard, we think the standards that have been set for camera trap data in biodiversity research (Forrester et al., 2016) are also applicable to ecological and evolutionary studies using camera traps to collect data on predation or other species interactions more generally.

Conclusions

In sum, our study confirms that videography enhances field studies of predation employing artificial prey. Videography not only allows predators to be identified but also permits predator-artificial prey interactions to be characterized. Our experiments demonstrate that videography allows "unattacked" replicas to be categorized into replicas that were never detected by predators and replicas that were detected but avoided. Videography also enhances the quality of data collected from field experiments. The high number of mismatches between clay-based scores and camera-based scores in our experiments is a testament to the ability of videography to enhance data quality. However, camera-trapping techniques have substantial financial and logistical costs that should be considered by researchers. Camera traps are unlikely to ever be employed at the scale of an entire field experiment in the near future if such high numbers of replicas are necessary for sufficient statistical power. If the realism of artificial prey could be augmented so that the frequency at which predators are engaged by such prey is increased, it might then be possible to employ camera traps at a higher proportion of replicas within a single experiment. More generally, our results suggest that camera trapping could provide a powerful tool to study a wide variety of species interactions in nature (e.g., mate choice, male-male competition, etc.).

Acknowledgements

We thank C. Porter for comments. We thank B. Edwin Siurob Espíndola, C. Iván Hernández Herrera, D. Joaquin Sánchez Ochoa, E. Hernández Martínez, S. Jovita González Ramos, J. Vaca Guerrero, and personnel at Tiputini Biodiversity station for help with fieldwork. We thank the Ecuadorian and Mexican government for providing the necessary research permits (Ecuador: N° 002-017 IC-FAU-DNB/MA; Mexico: SGPAJDGVS/09347/16).

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Figure 1

Locations of field experiments in the Americas.

Insets show habitat typical of the study areas (Orellana, Ecuador – *terra firme* and *varzea* rainforest; Chiapas, Mexico – Lacandon premontane wet forest; North Carolina, USA – longleaf pine forest).

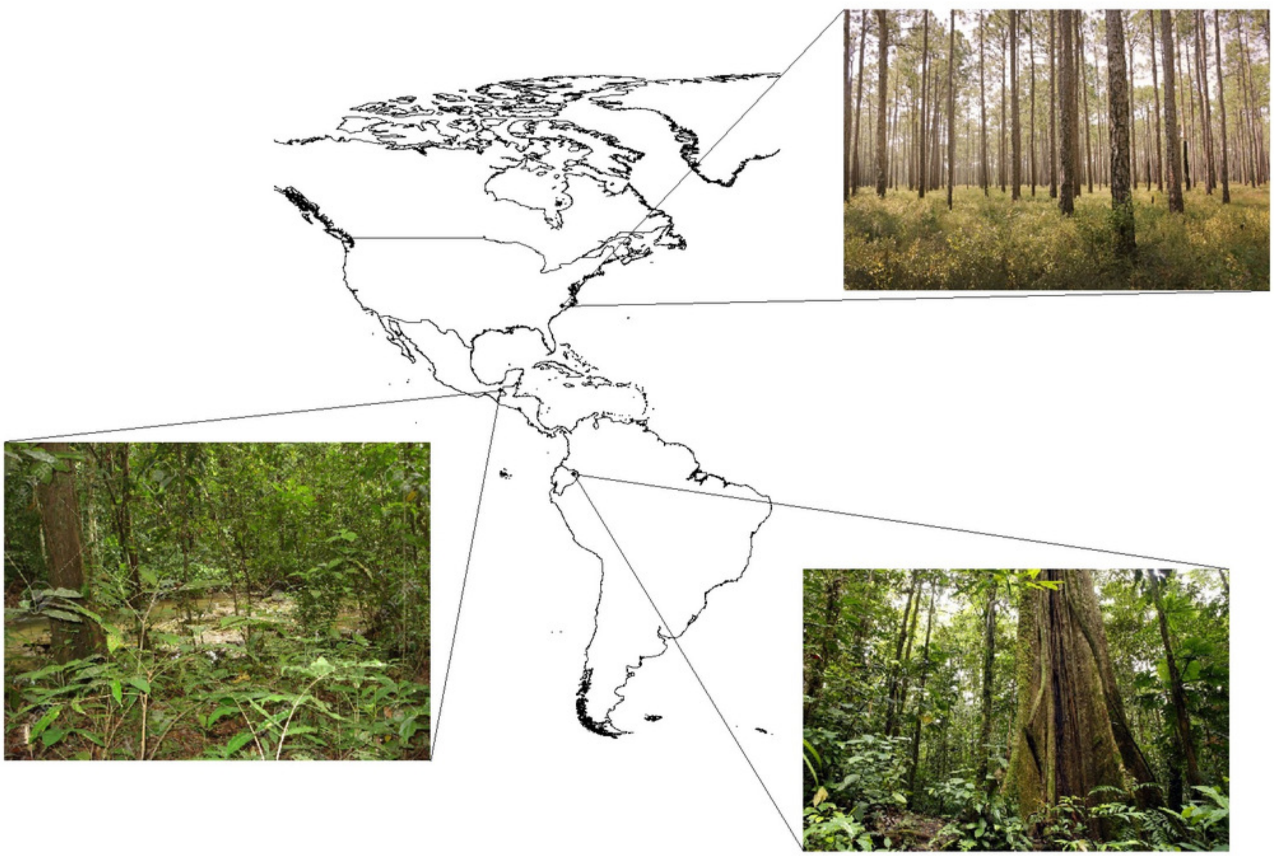

Figure 2

Collage of images from camera trap videos taken at several locations in the Americas where field experiments using artificial prey were conducted.

Top left: Gray-winged trumpeter (*Psophia crepitans*) biting a replica of an ornate coral snake (*Micrurus ornatissimus*). Top right: Collared peccary (*Peccari tajacu*) examining a replica of the South American coral snake (*Micrurus lemniscatus*). Bottom left: Gray fox (*Urocyon cinereoargenteus*) biting a replica of the variable coral snake (*Micrurus diastema*). Bottom right: Black bear cubs (*Ursus americanus*) examining replicas of the eastern coral snake (*Micrurus fulvius*).

Table 1 (on next page)

List of characteristics that varied among field experiments employing camera traps to monitor predator activity near artificial prey replicas of coral snake and coral snake mimics.

Table 1. List of characteristics that varied among field experiments employing camera traps to monitor predator activity near artificial prey replicas of coral snake and coral snake mimics.

Location of Field Experiment	Tiputini Biodiversity Station, Orellana, Ecuador	Nahá Reserve, Chiapas, Mexico	Sandhills and Coastal Plain, North Carolina, USA
GPS Coordinates	~0°37'S, 76°10'W	~16°58'N, 91°35'W	~34°45'N, 78°32'W
Date Conducted	2/12/17-2/26/17	6/20/17-7/22/17	10/17/2017-11/16/2017
Habitat(s)	Lowland *terra firme* and *varzea* rainforest	Premontane wet forest	Longleaf pine forest
Elevation	190-270 m	800-1,200 m	0-150 m
Study species	*Micrurus lemniscatus*, *Micrurus spixii*, *Micrurus ornatissimus*, *Micrurus hemprichii*	*Pliocercus elapoides*, *Micrurus diastema*, *Micrurus elegans*	*Micrurus fulvius*
Subject of study	Aposematism	Mimicry	Aposematism
Number of phenotypes	5 (4 *Micrurus* species + brown control)	4 (3 *P. elapoides* variants + brown control)	3 (3 *M. fulvius* variants)
Placement of replicas in transects	Singly, along forest trails, and 1-4 m off trails on alternating sides	Singly, along forest trails, and 1-4 m off trails on alternating sides	Each phenotype in groups of three through open habitat; all replicas attached to nails
Distance between replicas or sets of replica	5-10 m	5-10 m	50-75 m
Number of transects	27	35	20
Total number of replicas used in experiment	1,350	1,400	600

Minimum distance between transects	200 m	200 m	3 km
Number of days replicas (and camera traps) left in field	14	30	28
Interval at which replicas were checked during the experiment	2 days	6 days	Replicas not checked during experiment
Number of camera traps	32 (21 Spypoint Force-10; 10 Scout Guard SG560V-31B; 1 ANNKE C303)	22 (21 Spypoint Force-10; 1 ANNKE C303)	23 (21 Spypoint Force-10; 1 ANNKE C303; 1 Bestguarder DTC-880V)
Distribution of camera traps among transects	Random (cameras placed randomly among all transects in experiment)	Random (cameras placed randomly among all transects in experiment)	Clustered (cameras placed at every set of replicas within two transects and part of a third transect)
Distance between camera trap and replica(s)	1 m	1 m	2-3 m
Sensitivity of cameras (if sensitivity could be altered)	High	High	Medium

Table 2(on next page)

Comparison of camera trap results between field experiments.

Numbers in parentheses are numbers of detections or numbers of times behavior observed/# of trap-days. Detections indicate independent records (i.e., detections are records of species that are taken at the same site of the same species within 30 minutes of each other as a single observation). Attacks indicate instances where predators were observed to bite replicas from camera footage, while avoidances indicate instances wherein predators were observed to notice replicas but not attack them (see Materials and Methods for detailed description of how attacks and avoidances were scored). Interactions include both attacks and avoidances.

Table 2. Comparison of camera trap results between field experiments. Numbers in parentheses are numbers of detections or numbers of times behavior observed/# of trap-days. Detections indicate independent records (i.e., detections are records of species that are taken at the same site of the same species within 30 minutes of each other as a single observation). Attacks indicate instances where predators were observed to bite replicas from camera footage, while avoidances indicate instances wherein predators were observed to notice replicas but not attack them (see Materials and Methods for detailed description of how attacks and avoidances were scored). Interactions include both attacks and avoidances.

	Tiputini Biodiversity Station, Orellana, Ecuador	Nahá Reserve, Chiapas, Mexico	Sandhills and Coastal Plain, North Carolina, USA
Videos	527	705	660
Trap-days	414	637	476
Videos with non-human vertebrates	229	444	398
Detections of non-human vertebrates	181 (0.437)	402 (0.631)	323 (0.679)
Predator species detected	8	10	6
Videos with predators	88	57	178
Detections of predators	55 (0.133)	54 (0.085)	148 (0.311)
Detections of mammalian predators	37 (0.089)	53 (0.083)	144 (0.303)
Detections of avian predators	18 (0.043)	1 (0.002)	4 (0.008)
Predators interacting with replicas	14 (0.034)	7 (0.001)	31 (0.065)
Mammalian predators	12 (0.029)	7 (0.001)	31 (0.065)

interacting with replicas			
Avian predators interacting with replicas	2 (0.005)	0	0
Predators attacking replicas	2 (0.005)	6 (0.009)	10 (0.021)
Predators avoiding replicas	12 (0.029)	1 (0.002)	21 (0.044)

Table 3(on next page)

List of predator species that were detected at the locations where field experiments were conducted, categorized by whether the species did not interact, attacked, or avoided replicas.

Table 3. List of predator species that were detected at the locations where field experiments were conducted, categorized by whether the species did not interact, attacked, or avoided replicas.

	Tiputini Biodiversity Station, Orellana, Ecuador	Nahá Reserve, Chiapas, Mexico	Sandhills and Coastal Plain, North Carolina, USA
Did not interact	Brown nunlet (*Nonnula brunnea*) Slate-colored hawk (*Buteogallus schistaceus*) Ocelot (*Leopardus pardalis*) Nine-banded armadillo (*Dasypus novemcinctus*) Giant armadillo (*Priodontes maximus*)	Lesson's motmot (*Momotus lessonii*) Tayra (*Eira barbara*) Ocelot (*Leopardus pardalis*) Jaguarundi (*Puma yagouaroundi*) Common raccoon (*Procyon lotor*) White-nosed coati (*Nasua narica*) Striped hognose skunk (*Conepatus semistriatus*)	American Crow (*Corvus brachyrhynchos*) Wild Turkey (*Meleagris gallopavo*)
Attacked	Gray-winged trumpeter (*Psophia crepitans*) White-lipped peccary (*Tayassu pacari*)	Gray fox (*Urocyon cinereoargenteus*) Common opossum (*Didelphis marsupialis*)	Gray fox (*Urocyon cinereoargenteus*) Virginia opossum (*Didelphis virginiana*) Common raccoon (*Procyon lotor*) Black bear (*Ursus americanus*)
Avoided	Gray-winged trumpeter (*Psophia crepitans*) Collared peccary	Nine-banded armadillo (*Dasypus novemcinctus*)	Gray fox (*Urocyon cinereoargenteus*) Virginia opossum (*Didelphis

	(*Peccari tajacu*)		*virginiana*) Common raccoon (*Procyon lotor*) Black bear (*Ursus americanus*)

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