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RESEARCH ARTICLE

Testing camera traps as a potential tool for detecting nest predation of birds in a tropical rainforest environment

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ABSTRACT. Identification of the predators of bird nests is essential to test ecological and evolutionary hypotheses and to make practical management decisions. A variety of nest monitoring devices have been proposed but many remain difficult to set up in the field. The aim of this study was to test camera traps as a potential tool to study predation of natural nests in a tropical rainforest environment. Specifically, we registered the predators, assessed their size range, and we compared the use of one and two cameras per nest. Of 122 nests from 24 bird species, 45 (37%) were depredated, and the cameras recorded the predator species in 29 of the total of depredated nests (64%). We identified predators in eight of 16 depredated nests (50%) in which we used one camera trap per nest, and we identified predators in 21 of 29 depredated nests (72%) when we used two camera traps per nest. The predators included six species of birds and six species of mammals, with body masses varying from 20 g to 16.5 kg. Causes for 10 of the 16 detection failures were identified and are discussed. These results suggest that camera traps are viable tools to investigate nest predation in a tropical rainforest area.

KEY WORDS. Atlantic Forest, nest monitoring, nest predators, nesting success.

INTRODUCTION

Nest predation is often the primary cause of reproductive failure in birds, and because of its effect on fecundity, it is an important component of various hypotheses related to bird ecology, evolution, and conservation (Ricklefs 1969, Skutch 1985, Martin 1996, Martin et al. 2000). For example, the smaller clutch sizes in tropical birds compared to those of temperate species is hypothesized to be an anti-predatory response to reduce parental movements that could attract diurnal and visually oriented predators (Skutch 1949, Martin et al. 2000). Increased nest predation is also a potential cause of local bird extinctions in disturbed landscapes because populations of large carnivores decline, which leads to an increase in the density of mid-sized animals that are the primary nest predators (mesopredator-release hypothesis) (Oniki 1979, Robinson and Sherry 2012). However, many predictions of these and other hypotheses are surprisingly poorly tested because they require identification of nest predators.

Direct observation of nest predation is improbable because predation events are brief and many occur at night, when observers are less often in the field (Thompson III et al. 1999, Robinson and Robinson 2001). Furthermore, the number of nests that can be monitored by direct observation is often limited, which reduces the chances to detect a predation event. Therefore, a variety of photographic and video recording devices have been developed to monitor bird nests (Pierce and Pobprasert 2007). However, the primary limitation of most devices is the requirement of separate parts, e.g. cameras, batteries, and motion sensors, that are difficult to carry and to set up in the field (Pierce and Pobprasert 2007, Sabine et al. 2005, Grivas et al. 2009, Gula et al. 2010, Smith et al. 2012, Denmon et al. 2013). Digital video cameras that are currently available commercially (e.g. camcorders) could resolve this problem, as most parts are combined in a unique and compact device that generates high quality films and sounds (Mitchell et al. 2012). Additionally, digital video cameras are cost-effective and have memory for more than 60 hours of video recording. However, improvements in battery technology have not occurred as rapidly as those for memory, and for regular batteries, the typical use is 4–8 hrs, which prevents 24 hours per day monitoring. Long-standing batteries could be easily adapted but then the entire device is much less transportable. Furthermore, with continuous monitoring, too much time is required to review videos (Sabine et al. 2005, Pierce and Pobprasert 2007). Motion sensors can be used to generate data sets of a size easier to analyze but these sensors are not available in most cameras.

Alternatively, a new generation of camera traps can be programmed to take pictures or to film and has many of the advantages mentioned above. Additionally, these camera traps are equipped with motion and/or heat sensors that reduce the time of video monitoring without activity in the nest and power consumption, and use infrared light for night vision that replace the incandescent flashes of light that can scare nocturnal predators and interfere with the predation events (Meek et al. 2014). The camera traps also print relevant data on photographs and videos, such as time, date, and temperature (O'Brien and Kinnaird 2008). Camera traps have been successfully used, for example, to estimate the abundance of marked birds (O'Brien and Kinnaird 2008), to study habitat use (O'Brien and Kinnaird 2008, Srbek-Araujo et al. 2012, Kuhnen et al. 2013), diet (Renner et al. 2012, García-Salgado et al. 2015), social organization (Srbek-Araujo et al. 2012), daily and seasonal activity patterns (Srbek-Araujo et al. 2012, Kuhnen et al. 2013, Dias et al. 2016), nesting behavior (Rollack et al. 2013), and in a few recent studies, they were used to identify nest predators (Knight et al. 2014, Thiebot et al. 2014, Davies et al. 2015, Grendelmeier et al. 2015). In studies that identified nest predators, the delay in triggering and the inability to detect small predators were the primary potential drawbacks impeding broader use of camera traps (O'Brien and Kinnaird 2008).

In this study we tested camera traps as a potential tool to study nest predation in a tropical rainforest environment. Specifically, we registered the predators, assessed their size range, and we evaluated the efficiency of using one or two cameras per nest. We also determined the proper field procedures to reduce some of the causes of failure to detect predators. To our knowledge, this study is the first to use camera traps to monitor a variety of nests for predation within a bird community of a tropical rainforest.

MATERIAL AND METHODS

Fieldwork was conducted at Parque Estadual Carlos Botelho (24°06'55" to 24°14'41"S, 47°47'18" to 48 07'17" W) in the state of São Paulo, Brazil. The park is mainly primary Atlantic Forest and when the 37,644 ha are combined with adjacent protected areas, it forms one of the most important remnants of Atlantic Forest with more than 1.1 million ha. This Atlantic Forest remnant is one of a few in which the assemblage of top predators has not been drastically disturbed, with jaguars *Panthera onca* (Linnaeus, 1758) and cougars *Puma concolor* (Linnaeus, 1771) preserved (Brocardo et al. 2012). The altitude in the park varies from 20 to 1,000 m a.s.l., the average annual temperature varies from 18 ° to 20 °C, and the annual precipitation is 1,500–2,200 mm (Ferraz and Varjabedian 1999). In our study site, the vegetation is classified as submontane rainforest (Oliveira-Filho and Fontes 2000), and altitude ranges from 714 to 837 m.

We used 68 digital camera traps Bushnell TrophyCam, model 119437C (Bushnell Outdoor Products, Kansas, USA). These cameras are equipped with an infrared heat/motion sensor and take pictures or generate HD video clips. In low light exposure, the cameras can be adjusted to activate 8 or 24 infrared LEDs for videos, with results in black and white. The sensor level can be adjusted to Low, Normal, High, and Auto; with the Auto setting, the optimum setting is based on the ambient temperature.

Cameras were positioned 1–3 m from each nest, depending on the availability of adequate branches or saplings with which to tie the camera, except for three that were placed across a road (see discussion below). Brief nocturnal tests conducted in the study area revealed that at these distances, the use of 24 infrared LEDs would produce overexposed videos. As videos are intuitively better than pictures because they may distinguish better between the animals that only examine nest contents closely from those that indeed depredate the eggs or nestlings, in the present work the cameras were programmed to obtain 30 sec videos, with Low LED intensity (eight LEDs). As small predators could be present, we used "High" sensor level, with intervals of 3 sec between triggers, and the detections were stored on 2 GB memory cards.

We searched for natural nests three to five days a week from September to February during two breeding seasons (2013/2014 and 2014/2015). Nests were located by chance and by following adult birds in areas in which they presented territorial behaviors (Martin and Geupel 1993) along approximately 10 km of trails and streams in primary forest. The nests were checked every 1–3 days, and in late nestling stage the checks of nests intensified to avoid confounding predation with fledging. All bird species were considered, which included several families and different types of nests (open, closed and cavity).

In the 2013/2014 season, we only used one camera per nest, and in the 2014/2015 season, two cameras were used per nest. Independent of the camera recordings, predation was considered when the eggs or the nestlings disappeared from a nest.

Sampling effort (camera-days) in each nest was considered from the first day of monitoring (the day a nest was found), until the day of its fate (predation or fledging). Then, total sampling effort was calculated by summing the number of days of monitoring across all of the nests.

To evaluate the range size of predators recoded by camera traps, we assessed their body masses. For birds, the body mass was obtained from Handbook of the Birds of the World Alive (Del Hoyo et al. 2016) and Dunning Jr (2008), and for mammals the data was obtained from Reis et al. (2006).

To test the efficiency of using one or two cameras per nest for the detection of nest predators, we constructed a 2 × 2 contingency table in which rows contained the numbers of depredated nests with recorded predators, and the number of depredated nests with unrecorded predators found in each treatment. These proportions were compared between treatments using Fisher's Exact test with the software PAST version 2.17 (Hammer et al. 2001).

RESULTS

We found and monitored 122 nests of 24 bird species, with 40 nests in the 2013/2014 and 82 nests in the 2014/2015 breeding seasons, for a total of 2,604 camera-days. All of the nests were above ground, in understory vegetation or in ravines. Forty-five of the 122 nests were depredated (37%), 13 were abandoned (11%), one nesting branch fell down (0.8%), and three nests were destroyed by passing South America Tapirs *Tapirus terrestris* (Linnaeus, 1758) (2.45%) that were recorded by the cameras. We also observed that one of the abandonments (a nest of the Blue Manakin *Chiroxiphia caudata* (Shaw & Nodder, 1793)) was caused by the disturbance of vegetation from a Spotted Paca *Caniculus paca* (Linnaeus, 1758). Of the 45 depredated nests, the cameras recorded predation in 29 nests (64%) of 14 species of birds (Table 1). Two nests had partial predation, with two predation events in the same nest (one event for each of two eggs on different days). Then, in total we observed 31 predation events in 29 nests.

In the 2013/2014 breeding season, we identified predators in eight (50%) of 16 depredated nests using one camera trap per nest. In the 2014/2015 season, we identified predators in 21 (72%) of 29 depredated nests using two camera traps per nest. The proportion of depredated nests in which nest predators were identified was not significantly different with one or two cameras ($p = 0.62$), although only one of two cameras recorded the predation in eight (38%) of the 21 nests with recorded predations from the 2014/2015 season. The predators included six species of birds and six species of mammals, with body masses that varied from 20 g (Northern Three-striped Opossum) to 16.5 kg (Ocelot) (Table 1). Seven of the 31 predation events (23%) occurred at night (Table 1). Examples of predators are presented in Figs 1–4, and videos depicting nest predations are shown in Suppl. materials 1–5.

DISCUSSION

Our data suggest that camera traps are viable tools to investigate nest predation in a tropical rainforest area. A number of studies have used camera traps to monitor nest predation, and they frequently detect most of the predation events. For small passerines, Grendelmeier et al. (2015) successfully identified predators in 84% of 57 depredated nests of the Wood Warbler *Phylloscopus sibilatrix* (Bechstein, 1793) in northern Switzerland. Knight et al. (2014) identified predators in seven out of 10 depredated nests (70%) of the Vesper *Pooecetes gramineus* (Gmelin, 1789), Lark *Chondestes grammacus* (Say, 1823), and Brewer's Sparrows *Spizella breweri* Cassin, 1856 in a sagebrush habitat of North America. For other groups of birds, Thiebot et al. (2014) did not detect the causes of failures in three nests of the Amsterdam Albatross *Diomedea amsterdamensis* Roux, Jouventin, Mougin, Stahl & Weimerskirch, 1983 monitored with camera traps, whereas in Davies et al. (2015), the efficiency in detecting predators of 15 monitored Tristan Albatross *D. dabbenena* Mathews, 1929 nestlings was 100%, with all nests attacked by the House Mouse *Mus musculus* Linnaeus, 1758. Using a motion sensor device similar to camera traps (Memocam DVR unit) Bolton et al. (2007) detected predators in 74% of 19 depredated nests of Lapwings *Vanellus vanellus* (Linnaeus, 1758), and of the Spotted Flycatcher *Muscicapa striata* (Pallas, 1764). These evidences, and our data suggest that camera systems based on motion sensors rarely achieve 100% efficiency in the detection of predators, as occurs, for example, with most devices with full time recording (time-lapse devices) (Sabine et al. 2005, Pierce and Pobprasert 2007, Gula et al. 2010, Kirkpatrick and Conway 2010, Smith et al. 2012, Denmon et al. 2013).

We suggest that the optimal choice of a system to detect nest predators likely depends on the purposes of each study. Although the detection of predators is higher with time-lapse mechanisms, these systems remain complex and the number of nests that can be monitored is therefore limiting. Then, time-lapse mechanisms would be ideal for research that is based on the analysis of a small number of nests. In studies that involve bird communities, many nests can be monitored simultaneously with the use of camera traps and more information can be generated in a shorter period. Although these are advantages, information on the species and the frequency of nest predation could be flawed if camera traps fail to detect, for example, animals that are too small or too fast to activate the triggering mechanisms. However, there are evidences that this type of limitation is unlikely to affect most studies using camera traps. In our study area, the smaller mammals are the wild mice of the genera *Akodon* Meyen, 1833, *Brucepattersonius* Hershkovitz, 1998, *Juliomys* González, 2000, *Thaptomys* Thomas, 1916, and *Oligoryzomys* Bangs, 1900, and the marsupials Brazilian Gracile Opossum *Gracilinanus microtarsus* (Wagner, 1842), Grey Slender Mouse Opossum, and the Three-striped Short-tailed Opossum, which all weighed approximately 20 g or more (Reis et al. 2006,

Table 1. Predator species with body mass (kg), bird species, type of nest and numbers of depredated nests detected by camera traps in an area of Brazilian Atlantic Forest.

Predator species (body mass)	Bird species (nest type; number of depredated nests)
White-necked Hawk (*Amadonastur lacernulatus*) (Temminck, 1827) (0.61–0.71 kg)*	Star-throated Antwren (*Rhopias gularis*) (Spix, 1825) (open; n = 1)
	Blue Manakin (*Chiroxiphia caudata*) (Shaw & Nodder, 1793) (open; n = 1)
	White-throated Spadebill (*Platyrinchus mystaceus*) Vieillot, 1818 (open; n = 1)
Tawny-browed Owl (*Pulsatrix koeniswaldiana*) (Bertoni & Bertoni, 1901) (0.48 kg)	White-necked Thrush (*Turdus albicollis*)Vieillot, 1818 (open; n = 1)
Red-breasted Toucan (*Ramphastos dicolorus*) Linnaeus, 1766 (0.26–0.40 kg)	Ruddy Quail-Dove (*Geotrygon montana*) (Linnaeus, 1758) (open; n = 2)
	Rufous Gnateater (*Conopophaga lineata*) (Wied, 1831) (open; n = 1)
	Blue Manakin (open; n = 3)
	White-necked Thrush (open; n = 1)
Barred Forest-Falcon (*Micrastur ruficollis*) (Vieillot, 1817) (0.14–0.32 kg)	Star-throated Antwren (open; n = 1)
	Plain Antvireo (*Dysithamnus mentalis*) (Temminck, 1823) (open; n = 1)
	Blue Manakin (open; n = 1)
	Gray-hooded Flycatcher (*Mionectes rufiventris*) Cabanis, 1846 (closed; n = 1)
Collared Forest-Falcon (*Micrastur semitorquatus*) (Vieillot, 1817) (0.48–0.94kg)	White-necked Thrush (open; n = 1)
Buff-fronted Foliage-gleaner (*Philydor rufum*) (Vieillot, 1818) (0.02–0.04 kg)	Blue Manakin (open; n = 1)
	Southern Rough-winged Swallow (*Stelgidopteryx ruficollis*) (Vieillot, 1817) (cavity; n = 1)
Grey Slender Mouse Opossum (*Marmosops incanus*) (Lund, 1840) (0.02–0.14 kg)	Violet-capped Woodnymph (*Thalurania glaucopis*) (Gmelin, 1788) (open; n = 1)
	Star-throated Antwren (open; n = 1)
	Royal Flycatcher (*Onychorhynchus swainsoni*) (Pelzeln, 1858) (closed; n = 1)
	Yellow-legged Thrush (*Turdus flavipes*) Vieillot, 1818 (open; n = 1)
	White-necked Thrush (open; n = 1)
Three-striped Short-tailed Opossum (*Monodelphis americana*) (Müller, 1776) (0.02–0.03 kg)	Gray-hooded Flycatcher (closed; n = 1)
Southeastern Four-eyed Opossum (*Philander frenatus*) (Olfers, 1818) (0.22–0.68 kg)	Ruddy Quail-Dove (open; n = 1)
Black Capuchin (*Sapajus nigritus*) (Goldfuss, 1809) (1.40–4.80kg)	Star-throated Antwren (open; n = 1)
	Euler's Flycatcher (*Lathrotriccus euleri*) (Cabanis, 1868) (open; n = 1)
	White-necked Thrush (open; n = 1)
Ocelot (*Leopardus pardalis*) (Linnaeus, 1758) (7.20–16.50 kg)	Gray-hooded Flycatcher (closed; n = 1)
Tayra (*Eira barbara*) (Linnaeus, 1758) (3.70–11.1 kg)	Blue Manakin (open; n = 1)
	Sepia-capped Flycatcher (*Leptopogon amaurocephalus*) Tschudi, 1846 (closed; n = 1)

*Body mass estimated based on Rufous Crab Hawk *Buteogallus aequinoctialis* (Gmelin, 1788).

Brocrado et al. 2012). The Grey Slender Mouse Opossum, and the Three-striped Short-tailed Opossum were filmed in the nests, which indicated that the cameras were able to detect these small animals. Snakes require special attention because they can approach nests in a secretive way and in many studies are recognized as important nest predators (Roper and Goldstein 1997). In this study, although we did not observe snakes depredating nests, we filmed a small specimen of the genus *Echinanthera* Cope, 1894 passing in front of a nest of Gray-hooded Flycatcher, but the snake was apparently not attracted by the contents. Knight et al. (2014) used the same type of camera traps as those in this study and identified snakes as the primary predators of songbird nests in the sagebrush shrub-steppe of North America. These are evidences that our camera traps could detect snakes, particularly within the 1 to 3 m distance that is used in most studies.

The detection efficiency of predators (29 of 45 predation nests, 64%) was low in our study compared with other studies that used camera traps. However, of the 16 predation events that were missed, 10 were attributed to failures that included the following: three cameras had memory cards that were overloaded; three cameras were incorrectly positioned in relation to the nests; one camera had the supporting branch displaced by a heavy storm; and three cameras were likely positioned too far from the nests at 5–6 m. These errors could have been avoided with proper field procedures. In the other six nests, the failure to detect predation could not be attributed to any of these causes. Nest displacement was also a problem that frequently occurred when nesting branches were bent over with too much water after storms. Although we did not perform specific tests to evaluate the distance effect on predator detection efficiency, our evidence indicated that cameras placed 5–6 m from the nests were not effective. The cameras were positioned at this range for only three nests, which were cavities on the banks of a road in the park, and were placed on the other side of the road. These cameras recorded various large animals but did not detect predation events that were most likely caused by smaller animals. In our study, when the nests were eliminated for which the failure could be overcome with proper execution procedures and more often checking of the cameras, the detection efficiency increased to approximately 87%.

This study is the first to evaluate the efficiency of camera traps in the monitoring of nest predation in a tropical rainforest bird community. The camera traps offer a promising approach, particularly because the cameras could detect even the smaller potential predators that occurred in the area. We suggest that the correct positioning of cameras, the use of commercially available memory cards with higher storage capacity, and more

Figures 1–4. Predators of bird nests recorded with camera traps in an area of Atlantic rainforest. (1) the Collared Forest-falcon, *Micrastur semitorquatus*, depredating a nest of the White-necked Thrush, *Turdus albicollis*. (2) the Red-breasted Toucan, *Ramphastos dicolorus*, depredating a nest of the Ruddy Quail-dove, *Geotrygon montana*. (3) the Ocelot, *Leopardus pardalis*, depredating a nest of the Gray-hooded Flycatcher, *Mionectes rufiventris*. (4) the Gray Slender Mouse Opossum, *Marmosops incanus* depredating a nest of the Royal Flycatcher, *Onychorhynchus swainsoni*.

regular inspections of the cameras, particularly after storms, are important guidelines to increase the efficiency of predator detection. Further, the cameras permitted to identify other causes of nest disturbance not attributed to predation, e.g. nesting branch falling down, and disturbances caused by non-predator animals. Although the statistical significance of predator detection was not affected, we also recommend the use of two cameras per nest, because the predators were identified by only one of the cameras in many nests. In previous studies that used camera traps for a similar purpose, all were conducted in temperate habitats (Knight et al. 2014, Thiebot et al. 2014, Davies et al. 2015, Grendelmeier et al. 2015), but, based on the results of this study, camera traps are also appropriate to monitor nest predation in tropical rainforest environments.

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Supplementary material 1

Video of the Collared Forest-falcon, *Micrastur semitorquatus*, depredating a nest of White-necked Thrush, *Turdus albicollis*, containing three eggs. In this cloudy day, the infrared LEDs were activated.

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Data type: multimedia

Link: https://doi.org/10.3897/zoologia.35.e14678.suppl1

Supplementary material 2

Video of the Red-breasted Toucan, *Ramphastos dicolorus,* consuming an egg of the Ruddy Quail-dove, *Geotrygon montana.* Seven days later, a second egg present in this nest was also consumed by a Red-breasted Toucan.

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Data type: multimedia

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Supplementary material 3

Video of a nest of the Blue Manakin, *Chiroxiphia caudata*, being depredated by The Red-breasted Toucan, *Ramphastos dicolorus*. The video shows a young in late nestling stage being removed from the nest and being carried away by the toucan.

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Data type: multimedia

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Supplementary material 4

Video of an Ocelot, *Leopardus pardalis*, depredating a nest of Gray-hooded Flycatcher, *Mionectes rufiventris*. The video shows the moment in which a nestling try to leave the nest and is captured in the air by the Ocelot.

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Data type: multimedia

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Supplementary material 5

Video of a nest of the Gray-hooded Flycatcher, *Mionectes rufiventris*, containing two nestlings, being depredated by Three-striped Short-tailed Opossum, *Monodelphis americana*. Note that the small mammal has climbed the closed nest, found its entrance, and has invaded the interior of the nest.

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