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Evidence for Three-Toed Sloth (*Bradypus variegatus*) Predation by Spectacled Owl (*Pulsatrix perspicillata*)

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Abstract

We detected the nighttime death of a radio-collared three-toed sloth (*Bradypus variegatus*) with an automated radio telemetry system in a Panamanian moist forest. Forensic evidence collected at the fresh carcass, including five pairs of zygodactyl puncture wounds, and the consumption of only soft tissue, suggests that the predator was a large owl, probably *Pulsatrix perspicillata*. Telemetry data, feces in the sloths' rectum, and old sloth feces at the base of the tree near the carcass suggest that the sloth was descending to the ground to defecate when it was killed. If correct, this is the first record of *P. perspicillata* killing such a large prey, highlighting the importance of crypsis, and not self-defense, as sloths' anti-predator strategy. This event also suggests there are high risks for sloths climbing to the ground to defecate, a puzzling behavior with no clear evolutionary advantage discovered yet.

Key Words: BCI; Panama; predation; radio-telemetry; risk behavior; sloth

Predation risk has driven a diverse array of adaptations to allow animals to hide from, escape from, or fight against predators (Endler, 1991). Amidst these, body size has been identified as the most important effect on predator-prey interactions. Larger animals have fewer potential predators, with the very largest species, such as adult elephants, facing virtually no predation risk (Sinclair *et al.*, 2003). Predators are less likely to attack larger prey because they are harder to kill and are more likely to injure the attacking predators when defending themselves.

The relationship between the body size of predator and prey is well established across mammalian carnivores (prey mass = 1.19 predator mass; Carbone *et al.*, 1999) and predatory birds (Newton, 1979). The exceptions to this rule have come primarily from large predators eating small, superabundant prey, such as the sloth bear (*Ursus ursinus*, Shaw 1791) feeding on colonies of invertebrates (Carbone *et al.*, 1999). Here we report the possibility of an exception in the opposite direction, with predation of a large prey by a relatively small predator.

We conducted this work on Barro Colorado Island (BCI), Panama (1,500 ha; 9°10'N, 79°50'W), part of the Barro Colorado Nature Monument (5,500 ha total; Leigh, 1999). BCI is a hilltop that was isolated from the mainland in 1914 when the Chagres River was dammed to create Lake Gatun as part of the Panama Canal. The minimum distance between the island and the mainland is 200 m, although small islands break up this gap in some places. The habitat is moist tropical forest (Tosi, 1971; Leigh, 1999), and annual precipitation is approximately 2,600 mm, with a pronounced dry season (Windsor, 1990). The forest type is mixed, with both extensive second-growth regions as well as old-growth primary forests.

We caught a three-toed sloth on 13 March 2006 by climbing a tree using the single rope technique (Moffett and Lowman, 1995) and securing the sloth with a snare pole (Montgomery and Sunquist, 1975; Rattenborg *et al.*, 2008). The sloth was an adult female with a young of about four months. We did not separate the baby from the mother, but obtained a weight of the two together (6 kg) and estimated the weight of the mother to be 3.5–4.5 kg. We fixed a radio collar to the adult and immediately released both individuals together back into the forest canopy. The sloth's radio-collar was monitored by the Automated Radio Telemetry System (ARTS, <http://www.princeton.edu/~wikelski/research/index.htm>; Crofoot *et al.*, 2008; Lambert *et al.*, 2009).

The ARTS uses automated telemetry receivers mounted on seven above-canopy towers to monitor the location and activity of radio-collared animals through data relayed to the laboratory in real time (Crofoot *et al.*, 2008). It records the strength of signals from six fixed antennae on each tower and the changes in these signals can be used to estimate the activity of an animal (Cochran *et al.*, 1965; Kjos and Cochran, 1970; Lambert *et al.*, 2009). Data are transmitted back to the lab in real-time, so that the death of an animal can be quickly noted by the lack of an individual's activity (Aliaga-Rossel *et al.*, 2006). For the purpose of this paper, clear differences can be seen between three levels of activity: the highly dynamic signals of moving animals, the nearly static signals of resting animals, and the completely static signals from collars on dead individuals.

The strength of a signal from a radio-collar is dependent on the distance between the transmitter and receiver and the interference caused by terrain and

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vegetation between the two. Signals will greatly decrease if an animal moves into a hole, for example, or behind a large rock or tree. The height of a transmitter in the forest canopy also has a large effect on signal strength, with canopy transmitters typically being detected >10db stronger than those on the ground at the same location (Crofoot *et al.*, 2008).

At 21:20 h (± 2 min) on 13 March 2006 the signal from the radio-collared sloth began to slowly decrease in strength as received from three ARTS towers, consistent with a slow descent to the ground (Fig. 1). Because the three towers were all at different angles to the sloth, alternative explanations for this decrease in signal strength, such as climbing into a tree hole or on the backside of a very large tree, are excluded. At 23:00 h, the signal was completely static and did not change again. On the morning of 14 March 2006 we noticed the unchanging signals from the sloth collar and immediately went out to the field to check the condition of the sloth. We followed the radio-signal to find the dead sloth at the base of a large *Enterolobium cyclocarpum* (Jacq., Griseb) tree with several lianas. In addition to the sloth carcass, around the base of the tree we found a pile of fresh sloth hair and two piles of previously defecated sloth feces. Thus, based on the pattern of telemetry signals, presence of feces in the dead animal's rectum (*see below*), and the site of death apparently representing a preexisting sloth latrine, we conclude that the animal was likely climbing down to defecate when it was killed.

We brought the sloth carcass back to the laboratory for analysis and photographing, finding five paired sets of bloody puncture wounds (Fig. 2a–c). The ventral side of the sloth was facing up, with the belly skin cleanly removed (Fig. 2d). All of the sloth's internal organs were gone (Fig. 2e), although there were some fresh feces in the rectal area (Fig. 2f). Besides the bloody, zygodactyl (two-up, two-down) puncture wounds and empty body cavity, the rest of the carcass was undamaged. These paired puncture wounds are a very unique pattern, unlike the anisodactyl (one-up, three-down) talons of eagles, hawks, and falcons, and of the teeth bite marks of any mammalian predator. The paired, 2-2 zygodactyl talon pattern is rare in birds, and locally known only in trogons (Trogonidae, diurnal fruit eaters), woodpeckers (diurnal insectivores), osprey (Pandionidae, diurnal fish eaters), and owls (nocturnal predators). Of these, owls are the

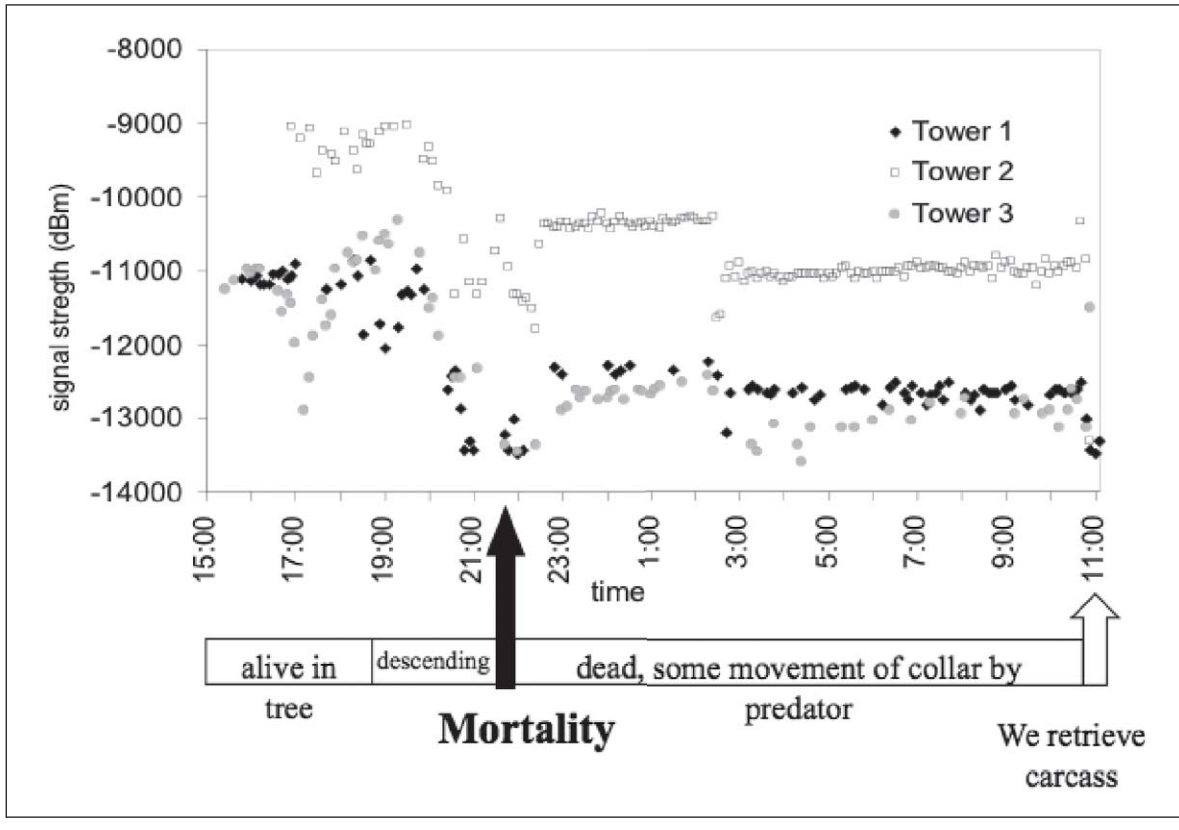


Figure 1. Time series of the signal strength of a sloth's radio-collar on the night of its predation as received by three automated telemetry receivers. Dynamic signal strength reflects animal activity while static signals indicate a resting or dead animal. Just before death all three towers registered a slow decline in signal strength, which we interpret as resulting from the animal descending a tree.

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most likely to kill a sloth at night. In particular, the spectacled owl (*Pulsatrix perspicillata*, Latham 1790, up to 1250 g) is the largest owl in our study site and the most likely predator of this sloth.

The treatment of the sloth carcass is also suggestive of a smaller predator, consistent with our suggestion of being an owl. The carcass was not thrown around or carried away to a nest, and only the softest tissue was eaten. Ocelots (*Leopardus pardalis*, Linnaeus 1758) are common on BCI, but are much more destructive eaters. Not only do they typically decapitate and remove limbs from their prey, but they also drag the carcass away from the site of death and then cover it with leaves at dawn (Aliaga-Rossel *et al.*, 2006). This three-toed sloth carcass was treated more delicately, as the lack of internal organs and paired puncture wounds were the only signs of trauma and the carcass was not moved from the kill site.

Sloths have not been reported in the diet of owls, but are commonly eaten by medium-sized and large felids (Sunquist and Sunquist, 2002; Moreno *et al.*, 2006) and eagles (Fowler and Cope, 1964; Galetti and Carvalho, 2000; Touchton *et al.*, 2002). We are fairly confident that the predator was not a harpy eagle (*Harpia harpyja*), as they were not known from BCI at the time, do not hunt in the



Figure 2. Diagram and photographs of freshly killed sloth. (a) Locations of five paired puncture wounds. (b) Close up views of punctures to side of the head and (c) the trapezius region of the back. (d) Ventral view of the cleanly disemboweled sloth carcass. (e) Close up view of the pericardial cavity and cleanly cut trachea, and (f) posterior view showing sloth feces in the rectum.

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middle of the night, and furnish talons with a large, easily identifiable anisodactyl spread. Spectacled owls are the largest owls found in the Neotropics, and are common on BCI. Gómez de Silva *et al.* (1997) found that, in Mexico, the majority of their diet is comprised of rats weighing approximately half their body weight. However, spectacled owls have been reported preying on a variety of larger species, including agoutis (*Dasyprocta* spp., Illiger 1811, up to 4 kg), opossums (*Didelphis marsupialis*, Linnaeus 1758, up to 2 kg), and skunks (*Mephitidae* spp., Bonaparte 1845, up to 4 kg) (Gómez de Silva *et al.*, 1997; Johnsgard, 2002).

Some owls are known to be well adapted to pin prey to the ground and feast on them at the kill site, instead of engaging in hawk-like swooping kills (Marti, 1974). Owls are also known to spread their toes just before an attack, increasing the cover area of the claw (Payne, 1962). Although pellet studies have yet to report sloths in their diets, little if any of the soft viscera eaten in this case would be identifiable in a regurgitated pellet. Previous studies on the diet of spectacled owls admit the obvious yet unavoidable bias towards only finding food that leaves remains in pellets (Gómez de Silva *et al.*, 1997).

Nearly every aspect of a sloth's lifestyle is adapted to avoid detection by predators. This includes its famously slow movement (Beebe, 1926), camouflaged pelage (Aiello, 1985), and uncanny ability to hide in the tree canopy. Its muscles and nerves are even developed to be slower in moment and response, further concealing its normal movements in the canopy (Goffart, 1971). Indeed, Montgomery *et al.* (1973) could only visually locate the sloths in their study five percent of the time, despite the fact that they wore radio-collars. Such extreme adaptation inevitably results in trade-offs. The three-toed sloth's elongated, mobility-reduced forearms and smaller, twisted hind legs aid its arboreal lifestyle, allowing efficient suspension from tree branches. However, these adapted appendages are all but useless on the ground, not supporting its body weight, thus forcing the sloth to awkwardly crawl about when not in the trees (Beebe, 1926). Sloths have a basal metabolism less than half of what is seen in other mammals their size (McNab, 1978) and often sleep for a long time, but not as much as previously suggested (Rattenborg *et al.*, 2008).

Here, we suggest another tradeoff associated with sloth metabolism — poor defense against predators leading to potentially being susceptible to a wider range of predators. Koalas (*Phascolarctos cinereus*, Goldfuss 1817, 4–14 kg) have adapted a similar, although less extreme, sedentary and arboreal lifestyle to the sloth. They are presumably inactive up to 16 hours a day and also have converged with sloths in having modified arms and legs, and a similarly low metabolism (Martin *et al.*, 1999; Grand and Barboza, 2001). Thus, for their body size, koalas are probably also relatively defenseless to predators, and they have also been found in the diet of raptors smaller than them (*e.g.* powerful owls, *Ninox strenua*, Latham 1802, up to 1700 g, and wedge-tailed eagles, *Aquila audax*, Latham 1802, up to 5300 g) (Melzer *et al.*, 2000).

This sloth mortality also potentially highlights one aspect of sloth behavior that is not obviously adapted to hide from predators: defecation. The sloth in our study was presumably climbing down a tree to defecate when it was killed. The sloth's ground-based defecation and urination remains one of the most enigmatic elements of its behavior, for which a convincing evolutionary explanation is still lacking. Sloths climb to the ground every three to eight days, dig a small hole with their stubby tail, defecate, and climb back into the trees (Britton, 1941; Goffart, 1971). The specific benefit to the sloth remains unknown, but theories include proposed benefits from fertilizing their favorite trees, communicating with other sloths through social latrines, or trying to hide their scent from predators (Beebe, 1926; Krieg, 1939; Goffart, 1971). A predation event as the one observed here highlights the risky nature of this ground-based defecation behavior, as does the high proportion of sloth in the diet of BCI ocelots, a felid not known to be a strong climber (Moreno *et al.*, 2006). We suggest that ground-based defecation behavior — existent in both genera of sloths despite obvious predation risks — will likely have a strong adaptive value that is yet to be discovered.

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